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Editor's Comments

Having been editor for this Journal for over a year now, one thing that I can't get over is the diversity of topics that cross my desk. As a scientist with a specific specialty field, I find that it's often easy to take for granted how ubiquitous science is. But it is exactly for this reason that I was first attracted to science.

Recently I've been seeing more advertisements for citizen science projects. I have to say that I love this idea. What better way to get the public involved and interested in science by making it accessible and asking for their participation?!?! This is particularly important to engage the younger generations.

As the summer months approach, I challenge all of our members to try to engage the public, and particularly younger students, in science and research. This can be accomplished through informal talks, blog posts, newspaper articles, mentoring programs, science fairs, and the list goes on. If you are looking for some good citizen science projects, I recommend referencing www.scienceforcitizens.net. This is a fairly comprehensive list of research projects that are recruiting citizens to assist. This could be a great way to engage students during their summer break.

I encourage you to get creative in engaging your students, family members, friends, and neighbors. This is an opportunity to share the passion that we all have for the science world.

This issue of the Journal is a great demonstration of the diverse nature of scientific research. The first article, *Grain, Pulses, and Olives: An Attempt toward a Quantitative Approach to Diet in Ancient Rome*, authored by Madeline Brown, takes a comprehensive approach to determining the diets of Romans in Ancient Antiquity. Ms. Brown conducted this research during a ten week internship at the National Museum of Natural History following her graduation from Brown University. Following this is an article by Sethanne Howard exploring those 'wrinkles in space time' referred to as the Cosmic Microwave Background. *The Cosmic Microwave Background, Songs in the Universe* explains CMB experiments and what they tell us about how the universe came to be. Lisa Frehill and Kathrin Zippel then present *Gender and International Collaborations of Academic Scientists and Engineers: Findings from the Survey of Doctorate Recipients, 2006*, where they focus on gender differences among doctoral scientists and engineers when examining the extent to which they collaborate internationally. Finally, we present the minutes from the WAS

2nd annual Science is Murder event, during which authors Lawrence Goldstone, Ellen Crosby, Louis Bayard, and Dana Cameron talked about their use of science and incorporation of research into their murder mysteries.

Enjoy!

Jacqueline Maffucci, PhD
Editor, Journal of the Washington Academy of Sciences

INSTRUCTIONS TO AUTHORS

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3. Graphics (photographs, drawings, figures, tables) must be in graytone only (no color accepted), and be easily resizable by the editors to fit the Journal's page size. Do not wrap text around the graphics.
4. References (and bibliography, if included) may be in the format generally acceptable for the disciplinary or professional field represented by the manuscript. They must be accurate, complete, and consistent in format throughout the paper.
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American Registry of Pathology
Living Oceans Foundation

Grain, Pulses and Olives: An Attempt toward a Quantitative Approach to Diet in Ancient Rome

Madeline Brown
Smithsonian Institution, NHRE Summer 2010 Intern

Forward

The paper that follows is the first article by Madeline Brown. In May 2010, she obtained a degree in Anthropology from Brown University and, exactly two days later, she was at the National Museum of Natural History of the Smithsonian Institution. With seventeen other college students, she had been selected for a ten week NHRE Internship (Natural History Research Experience Internship). Based on her major in Botany and Ethnobotany, and her interest in Classical Culture (including a class on Roman food), Madeline Brown was directed to my unit, which specializes in the study of medicine, botany, and medicinal plants in the Mediterranean world from the most remote antiquity to the dawn of modern science. I suggested that she explore Roman diet as a possible source of the Mediterranean alimentary tradition. The present article is a presentation of her research, which was entitled "What did ancient Romans eat, and why?" This is the first essay by a freshly graduated student who will probably become a member of the future scientific community. It results from ten weeks of hard work, often late in the evening in the empty US National Herbarium, taking advantage of the *Historia Plantarum* collection and the documentation and knowledge accumulated in the Institute for the Preservation of Medical Traditions. However limited it will probably be considered, this essay opens the way for future research and is the first announcement of a scientist in-the-making.

I am grateful to the Washington Academy of Sciences and the Smithsonian Institution, and also to the Institute for the Preservation of Medical Traditions, for opening their doors to the next generation of scientists and offering them an opportunity to communicate their work, their ideas, and their enthusiasm for the scientific enterprise.

Alain Touwaide
Smithsonian Institution

Introduction

The dietary habits of Romans in Classical Antiquity have been discussed and qualitatively reconstructed in a number of previous studies, but none of these prior efforts have approached both its nutritional and biological properties in a comprehensive or systematic way. In addition, modern dieticians and scholars alike have been interested in the contemporary Mediterranean diet ever since Ancel Keys began his landmark research in the 1950s on the potential health benefits experienced by those who eat traditional Mediterranean diets (Keys, 1970). Yet despite popular interest in this "traditional" Mediterranean diet, little work has been conducted that attempts to uncover the true origins or the cultural, biological, and nutritional properties of this professed traditional diet. The aforementioned paucity of nutritional and biological quantification in previous studies on the ancient Roman diet may, in part, be responsible for the fact that few connections have been made between the diets of the ancient Romans and those of contemporary Mediterranean people. This pilot study suggests that research examining the actual biological and nutritional properties of the ancient Roman diet may enable us to better understand both the origins of the contemporary Mediterranean diet as well as how this diet has changed over the past two millennia.

In this study, the ancient Roman diet is defined as the range of foodstuffs likely eaten in the Mediterranean region from the second century BC up through the fifth century AD. These ranges of time, region, and foodstuffs have been determined by the time period, geographic coverage, and food items that can be traced through the seven primary texts referred to throughout this study. In addition, while the Roman Empire spanned a wide range of areas in Europe, Africa, and the Middle East, this pilot study focuses on the Mediterranean parts of the Roman Empire, specifically Rome and greater Italy. Regional variations in the types and quantities of available foodstuffs undoubtedly occurred throughout the Roman Empire and warrant examination by further studies on the quantification of ancient nutrition.

Prior studies on the nutritional properties of the ancient Roman diet have tended to focus on the few food groups, such as cereals and vegetable oils, for which there is fairly concrete textual evidence regarding the extent of their dietary contributions. Garnsey (1998) has made perhaps the most thorough attempt thus far to quantify the caloric and nutritional properties of Roman diets. Based on classical literary references regarding

the different amounts of grain allotted to various members of Roman society, he calculated the caloric contribution of cereals to the diets of members of each strata of Roman society (Garnsey, 1998). For example, Garnsey concludes that the approximately 33 kg, or five modii (modius being an ancient Roman unit of measure, with one modius equal to about 6.6 kg) of grain per person per month provided under the Roman state's *frumentatio* (the allotment of grain provided to Roman citizens by the state) during the 1st century AD would have been enough grain to provide about 3,700 kcals per person per day. Garnsey (1998: 229-230) notes that this amounts to almost twice the daily energy needs of an average human being. It must be noted however, that much of this grain would have been both inedible (due to prolonged storage and slow distribution) and contaminated with rocks, dirt or other heavy debris, which would have to be removed from the grain during the winnowing and cleaning process before it could be consumed. Therefore, it can be assumed that ancient Roman citizens receiving the *frumentatio* would not have actually had access to the full amount of grain (and therefore calories) in their 33 kg allotment.

In addition, Garnsey (1998: 236-237) found that Cato's recommended three modii (c. 19.8 kg) of grain per month for shepherds and estate domestic staff would provide c. 2,200 calories per day, while the four modii (c. 26.4 kg) for agricultural laborers (or slaves) provide c. 2,960 kcals per day. In another notable study, Foxhall and Forbes (1982) suggest that the ancient Romans obtained around 75% of their daily caloric needs from cereals. Other scholars maintain however, that this calculation is merely an estimate, and probably a high one (Garnsey, 1998; see also Schneider, 2006: 916).

While these previous studies provide useful frameworks for thinking about the role of grain as a source of food energy for the Roman people, none of them take their quantification methods further in an effort to understand the nutritional properties of the Roman diet as a whole. This study attempts to reconstruct the diet of early imperial period Romans, that is, the inhabitants of Rome and Italy from around the second century BC to the fifth century AD, by expanding on the quantitative methods from previous studies on cereal consumption in ancient Rome and instead quantifying not only the nutritional properties of its cereal components, but also the nutritional properties of the Roman diet as a whole. This is accomplished by determining both the individual and combined nutritional properties of all of the foods that were likely part of the Roman menu. Necessarily, this research relies on literary, archaeological, and botanical

data in order to both develop a comprehensive list of plant and animal species that are likely to have been eaten by the ancient Romans as well as to determine how these specific foods contributed to the overall health of the Roman people.

Moreover, by combining modern Mediterranean dietary data with what little is known about consumption patterns in ancient Rome, this pilot study employs a more comprehensive method of quantifying the general nutritional properties of ancient diets than has been used in the past. The results of this analysis suggest that the high quantities of cereals (namely wheat and barley) eaten by ancient Romans may have been sufficient enough to provide the majority of their nutritive needs, with the exception of vitamins A, C, and D, which they instead must have obtained from fruits, vegetables, and exposure to the sun. This pilot study provides a model for one method of quantifying the nutritional and biological properties of the Roman diets and will hopefully help begin to lay the groundwork for introducing further quantification and more holistic evaluation methods into studies on a variety of ancient diets.

Methods

Primary Sources

This study relies on a review of both primary sources and secondary literature discussing the Roman diet, from which a preliminary list of 321 different foods that the ancient Romans likely consumed was developed. Seven primary sources were surveyed to obtain quantitative data on Roman literary references to food (see Table 1). While this cross-section of Roman literature covers only a small percentage of the total classical texts available, it represents a useful and informative selection that is ideally situated for this initial quantitative investigation into the Roman diet. These texts were selected for their focus on ancient Roman food, agriculture, and dietetics, with the acknowledgment that they are a limited selection and of the potential for expansion in both the number and types of literary and other (archaeological, inscriptions, artistic) lines of evidence in future studies. This study drew methodological inspiration from Alain Touwaide's database of medicinal plants found in classical literature. Following in the methodological footsteps of the Touwaide database, this study expanded upon the preexisting database by determining and focusing on the various food plants and animals (rather than strictly medicinal plants) that are mentioned by ancient Roman authors. Specifically, I referred to the indices and concordances for each

of these texts (both in their original languages and translation for clarity) and documented how frequently the texts mentioned each of the 321 food items that were likely eaten by the ancient Romans (Briggs, 1983; Dioscorides, 2005; Striegan-Keuntje, 1992).

Table 1: Primary Sources Surveyed

Period/Date	Author	Title	Edition
234 – 149 BC	Cato	*De agricultura*	Hooper and Ash 1934
116 – 27 BC	Varro	*Rerum rusticarum libri III*	Hooper and Ash 1934
1st century AD	Columella	*De re rustica*	Rodgers 2010
23/24 – 79 AD	Pliny	*Naturalis historia*	Rackham, Jones, and Eichholz 1938 – 1962
4th century AD	Apicius	*Apicius*	André 1987
4th – 5th century AD	Palladius	*Opus agriculturae*	Rodgers 1975
511 AD	Anthimus	*De observatione ciborum ad Theodoricum regim Francorum epistula*	Paolucci 2003

In addition, numerous secondary literature texts were surveyed in order to gain a more informed perspective on the state of research on the dietary properties of the ancient Roman diet (Couplan, 1994; Toynbee, 1973). Several particularly informative texts from this survey are highlighted in Table 2.

In order to accurately analyze the number of times each ancient author mentions a particular food source, the total number of food names analyzed in the dataset corresponds to the total number of unique Latin or Greek food names, rather than to the number of different biological species that these names may represent. This prevents the over-representation of certain foods such as acorns, for which there are four possible species, but only a couple of more generic names in both Latin (*glans*) and Greek (*balanos* or *drus*), which may refer to any of the four different oak species. Therefore, the number of times that the word *glans* appears in the primary sources is recorded as only a single data point (for "acorns") rather than four (one for each oak species) in order to prevent an overrepresentation of acorns in the literature analysis.

Table 2: Notable Contributions from Secondary Literature

Date	Author	Title	Brief Description
1947	Thompson	*A Glossary of Greek Fishes*	Examination and identification of the fishes mentioned in Greek texts.
1981	André	*L'alimentation et la cuisine a Rome*	Overview of Roman cuisine and eating habits organized by culinary categories such as fruits, vegetables, meats, etc. Provided cultural context of Roman dining as well as framework for forming initial list of Roman foodstuffs.
1985	André	*Le noms de plantes dans la Rome antique*	Scientific and Latin identifications of plants utilized in ancient Rome.
2002	Jashemski and Meyer	*The Natural History of Pompeii*	An archaeological examination of organic materials from Pompeii. Provided some archaeological and artistic verification of the identities of foods in Roman diet.
2003	Dalby	*Food in the Ancient World: From A to Z*	Encyclopedia of culinary terms, foodstuffs, and other entries related to food and drink in the ancient world. Crucial in helping form initial list of possible Roman foodstuffs.

Biological Species Verification

Floras of Italy, botanical texts and archaeological evidence from Pompeii were used to identify the plant species found in the Roman diet according to contemporary Linnaean taxonomy (Pignatti, 1982; Van Wyk, 2005; Jashemski, 2002). Determining the scientific names of the otherwise generically named food items was a crucial step in ensuring that the nutritional data used in this study were drawn from geographically appropriate species whenever possible. In addition, verifying the biological identities of foods in the Roman diet allowed us to determine where the plant food items would have originated. Binomial designations of plants have been verified for accuracy using the *Flora Europaea* (Tutin *et al.*, 1980).

Nutritional Information

Quantitative nutritional data for the plant food items included in this analysis were gathered from the "USDA National Nutrient Database for Standard Reference," which draws its information from the "Nutrient Data Laboratory" of the USDA's Agricultural Research Service. Nutritional information on the amount of calories, iron, sodium, protein, fat, vitamin A, vitamin D, vitamin C, calcium and sugar per 100 g was compiled for 309 different foods that were likely eaten by the ancient Romans.

In gathering these data however, it was not always possible to find the exact nutritional information for each species. In these cases, nutritional data from a closely related species was included instead as a substitute for the missing information according to a procedure that was also frequently used in antiquity (that is, substituting one species for another based on availability). For instance, since there is no publicly available quantitative nutritional data for wild radish (*Raphanus raphanistrum* L.), the nutritional data from the closely related cultivated radish species (*Raphanus sativus* L.) was substituted as a nutritional analog. In general, most substitutions of plant or animal species were limited to other species within the same genus (or in some cases, the same family) as the desired species. In those instances when no nutritional information was available for all closely related species of a given food, data from a species with similar growth habits, exploited anatomical parts, or secondary metabolites to those of the species with missing nutritional data were inserted instead. This substitution method was employed primarily in constructing the original dataset, and does not alter the presentation of this study's results.

Nutritional information for the meats was taken from the USDA data on those meat products that most closely resemble the form in which the meat came off of the animal. For instance, the USDA's nutritional data for "Pork, fresh, carcass, separable lean and fat, raw" was chosen over other potential nutrient datasets such as "Pork, cured, ham, center slice, country-style, separable lean only, raw" or "Pork, ground, 96% lean / 4% fat, raw," as the nutritional information from a less processed meat product is more likely to resemble the nutritional profile of the meats that were available to the ancient Romans.

In addition, grass-fed or wild varieties of animals and plants were used whenever possible in an attempt to further mimic the plant and animal varieties found in ancient Rome, which were undoubtedly both less

domesticated and less selectively genetically engineered compared to most of our contemporary commodity crops and livestock.

Foods that are composed of a variety of ingredients (such as cake, bread, beer and aphye) are not included in the nutritional analysis because the exact ingredients, processing methods, and proportions of ingredients for each ancient recipe are currently unknown, and therefore the more general nutritional properties of these food items are also largely unknown. In addition, wine was not considered in this study, as the classical texts give no clear indication of its frequency of consumption by the ancient Romans, and therefore no indication of its possible nutritional role. Future studies expanding upon this initial quantitative analysis of the Roman diet could significantly improve our understanding of ancient Roman nutrition by considering the dietary role of these additional processed foods such as beer, wine, cakes, and garum.

Nutrition Guidelines

The nutritional analysis in this study focuses on 10 of the most important and essential nutrients required for proper human nutrition: calories/energy, protein, fat, sugars, calcium, iron, sodium, vitamin C, vitamin A, and vitamin D.

This study referred to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations' joint recommended daily intake data for vitamins and minerals as the baseline recommended daily amount for the following nutrients: calcium, iron, vitamin C, vitamin A, and vitamin D (WHO and FAO, 2004). In order to compare the Roman diet's nutritional adequacy for both men and women, our analysis included information on the daily intake required for both adult women (19-50) and adult men (19-65). In calculating the daily recommended amount of iron based on the WHO's data, the recommended amounts for the middle values of iron bioavailability (12% and 10%) were averaged, as information on the bioavailability of the types of iron in the Roman food sources was unavailable.

Besides using FAO and WHO guidelines, this study referred to the recommended daily intake values for protein, fat, sugars, sodium, and calories given by the Confederation of the Food and Drink Industries of the European Union's (CIAA) Guideline Daily Amounts (GDA) (2010).

Nutritional Analysis of Diet

Because definitive quantitative data on the amount of food consumed by ancient Romans is unavailable, studies on Roman nutrition must instead rely on the information that *is* known, such as the amount of grain provisioned to slaves or soldiers, and relate it to data about contemporary food consumption patterns. Along these lines, this study analyzed the ancient Roman diet using data from the FAO about the amount and proportions of foodstuffs annually consumed by contemporary Mediterranean people. Because the FAO divides diets into categories such as cereals, meats, and vegetable oils, it was possible to estimate the relative amount of nutrients that ancient Romans would have gained from each of these food groups by inserting food items from ancient diets rather than those from modern diets into the appropriate culinary categories.

Specifically, this study referred to the FAO's data regarding the total amount of food available for consumption in Spain, Italy, Greece, and Turkey during the year 1961 (which is the earliest year in which the FAO collected food consumption data). This information was further broken down into the total amount of cereals, starchy roots, sugar crops, sugar and sweeteners, pulses, tree nuts, oil crops, vegetable oils, vegetables, fruits, stimulants, spices, alcoholic beverages, meat, offal, animal fats, eggs, milk, fish and seafood, other aquatic products, and miscellaneous foods. The total kilograms of food available per person per year for each of these countries was then averaged in order to get a general idea of the amount and types of foods consumed by people in the greater Mediterranean. This contemporary information on food consumption provides a baseline idea of the total quantity of food consumed by a single person in a year, as well as how much of each type of food (cereal, meat, fruit, *etc.*) people in the Mediterranean consume relative to other types of food.

There are several key problems inherent in analyzing ancient diets using modern dietary data. While human diets exhibit strong cultural traditions and resilience in their basic components, they also are known to rapidly change to incorporate new foodstuffs made possible by new technology, trade, or other factors. In addition, during the last century, and particularly the last fifty years, human diets have undergone remarkably drastic changes as a result of the increased industrialization of food production and innovative food technologies, as well as unprecedented levels of global trade in agricultural commodities. Therefore, few people today continue to eat the "traditional" foodstuffs that they did several

hundred years or even several decades ago. A second difficulty arises from the differences between the dietary emphases of different food categories (such as meat, dairy, fruits, etc.) of modern and ancient peoples. For instance, contemporary people tend to eat more meat and sugar than those of the past, as unlike in ancient times, both of these food items are now generally no longer expensive, rare, or considered to be luxury foods. These considerations had to be taken into account while conducting this analysis of ancient nutrition using contemporary data about consumption levels.

Developing a Model Diet: Grain Consumption as a Baseline

Fortunately, the dietary shifts that have occurred since antiquity can be corrected for using the few known quantities of foods that were likely consumed by the ancient Romans, such as the amount of grain. The baseline amount of cereals consumed in the modern Mediterranean diet (according to FAO statistic) was adjusted in order to match the levels of ancient Roman grain consumption suggested by previous studies (Schneider, 2006; Garnsey, 1998; Foxhall and Forbes, 1982). As grain consumption is the only food category with clear ancient textual evidence of its consumption levels, this known quantity of ancient grain consumption provides the foundation upon which this study builds the rest of its nutritional reconstruction of the ancient Roman diet.

Based on past analyses of the Roman diet using Cato's aforementioned writings (Hooper and Ash, 1934) on grain allotments, it has been suggested that the amount of grain allocated to a typical Roman soldier or slave probably fell somewhere between 230 – 330 kg per year (Schneider, 2006: 916). These known quantities of high and low limits of grain consumption from antiquity were incorporated into the contemporary food-intake dataset as the high and low estimates of the relative contribution of grains to the Roman diet.

While these amounts of grain may seem high compared to modern levels of consumption, they must be considered within the context of the heavily grain-based ancient diet. According to Pearson (1997:15), during the later Carolingian era, one Anglo-Saxon guideline suggested providing 1.5 – 2 kg of bread per day, as well as additional meat and veggies. These amounts of grain rations are far higher than the intake amounts suggested by classical literature (Cato; Varro; Columella; Pliny; Apicius; Palladius; and Anthimus) and yet, there is clear documentation from throughout the early Middle Ages of a variety of monastic and lay rations of bread

allotments ranging from 330 g per day up to 1,700 g per day (Pearson, 1997). These medieval bread rations may help to better contextualize the low and high amounts of ancient Roman grain consumption suggested in this study. Two-hundred and thirty kilograms of wheat per year averages out to about 630 g per day, while 330 kg per year averages out to 870 g per day. According to the USDA Nutrient Data Laboratory, 100 g of durum wheat contains 339 kcal. Therefore, these high and low amounts of grain consumption would provide between about 2136 kcal and 2929 kcal per day, which are acceptable amounts of caloric intake for active males relying on a cereal-based diet.

Since the ancient Roman diet contained a higher proportion of cereal than the modern Mediterranean diet, this substitution increases, and thereby skews the total mass of food consumed per person per year. To correct for this, the amounts of all non-cereal food items were decreased proportionally so that the total kilograms of food consumed per year remained consistent with the original pre-adjustment amounts. In addition, after making this correction, the proportions of all non-cereal foods in the model diet remained the same as in the original pre-corrected model. This created a nutritional model for the ancient Roman diet based on a realistic amount of total food consumed per year in the contemporary Mediterranean diet. In addition, this method conserved realistic proportions between the different types of non-cereal foods while also enabling the simulation of a cereal-heavy diet that more closely resembles that of the ancient Romans (rather than the modern Mediterranean people).

An analysis of our results after these initial calculations revealed that the introduction of higher amounts of cereals (which are calorie-dense foods) actually altered the dataset to be unrealistically high in calories. To adjust for this, the total amount of food consumed per person per year was recalculated, this time including only those items that are known from primary sources and archaeological evidence to have been commonly consumed in the ancient Roman diet. This left us with a dataset containing information on the annual consumption of the “core” food categories in ancient Roman diets, that is, cereals, pulses, tree nuts, oil crops (olives, sesame seeds, etc.), vegetable oil, vegetables and starchy roots, fish and seafood, spices, and eggs. Notably, milk, meat and fruit were taken out of the “core” dataset, as the classical texts (Cato; Varro; Columella; Pliny; Apicius; Palladius; and Anthimus) suggest that the ancient Romans seem to have not consumed these foods other than on an irregular or seasonal basis. In addition, while it is well known that all Roman citizens, regardless of class, had access to meat during public festivals throughout

the year, it is not well known exactly how many animals were slaughtered or how the meat was distributed at each of these festivals, and therefore what the nutritional role of meat would have been for the Roman people. Therefore, this initial study does not consider meat as being a significant part of the Roman diet, as it is yet unclear how regularly or in what quantities meat was actually consumed.

Once the core categories of food in the Roman diet were established, the amount of food likely consumed by a Roman person from each of these categories in an average year was calculated. By combining this information (on total mass of food consumed) with information on the average nutritional properties (that is the amount of calcium, fat, etc. per 100 grams) of each food, it was possible to create a general model of the dietary profiles of people who consume the types of foods that the Romans ate in the same relative amounts and proportions (as determined using the previously discussed model). In addition, the high and low bounds of grain consumption also provide analogs for the nutritional profiles of both the lower and middle-to-upper classes in Roman society, as lower class individuals would have relied more heavily on grain, while those of upper and middle classes likely enjoyed a more varied diet.

Results

Foods Mentioned in Primary Sources

Based on this survey of seven primary sources that discuss food and agriculture in the Roman Empire, it is clear that ancient Roman authors mentioned some types of food far more frequently than others. This information has been essential for determining and confirming the types of foods eaten by the ancient Romans, and thus the types of foods included in this study's nutritional analysis.

Table 3: Mentions of Unique Foods in Primary Sources
(listed chronologically)

Classical Author	Number of Unique Foods Discussed
Cato	63
Varro	86
Columella	141
Pliny	117
Apicius	128
Palladius	136
Anthimus	56

The total number of different foods mentioned by the classical Roman authors surveyed in this study varies greatly (see Table 3). Altogether they mention 225 different foods, though as previously mentioned, some of these Greek and Latin names of foods may correspond to multiple biological species. The top ten foods mentioned in the classical texts that were surveyed in this study are indicated in Table 4. The wide variation in the frequency of literary references per food is apparent even in these top ten items. Furthermore, only 26 of the 225 different food items found in the ancient texts are mentioned over 100 times; by contrast 44 different foods are mentioned five times or less. This indicates that while ancient authors clearly had knowledge of a wide repertoire of culinary options, they in fact focused their discussion of food and dietetics on a more limited number of foods.

Table 4: Top 10 Food Items Mentioned in Seven Classical Texts

Food Item	Number of Times Mentioned
Black pepper	463
Wine	368
Grapes	305
Honey	266
Vinegar	253
Figs	244
Barley	210
Rue	206
Lovage	189
Olives	181

Nutrition

Using both high and low estimates of ancient Roman cereal consumption (230 and 330 kg per year respectively), this study generated two different profiles of the nutritional properties of ancient Roman diets depending on whether one assumes it contained higher or lower proportions of cereal compared to the overall amount of food consumed (Table 5). Assuming the Romans consumed the higher level of wheat intake (330 kg per year), and using the quantitative methods previously outlined, this study found that the total mass of food in the Roman diet following this model would have been 65% cereals, 28% vegetables and starchy roots, 2% fish and seafood, 1.8% vegetable oils, 1.1% pulses, 0.9% eggs, 0.8% tree nuts, 0.4% oil crops, and 0.1% spices. Assuming a lower level of wheat consumption (230 kg per year), these values shift so

that the dietary mass is 50.4% cereals, 39.6% vegetables and starchy roots, 2.8% fish and seafood, 2.5% vegetable oils, 1.6% pulses, 1.2% tree nuts, 1.2% eggs, 0.6% oil crops, and 0.2% spices.

Table 5: Amount of Nutrients in Roman Diet Based on Daily Recommended Nutrient Quantities (percentages)

		Iron	V. C	Prot.	Cal.	V. A	Fat	Calc	V. D	Salt	Sug.
Men	*Low**	285.8	224.1	170.5	117.2	121	83.2	68.2	42.9	12.4	10
	High	357.3	180	217.9	150.1	95.3	82.4	70.4	33.7	10.4	9.2
Women	*Low*	133	224.1	204.6	146.6	145.2	95.1	68.2	42.9	12.4	12.3
	High	166.4	180	261.5	187.6	114.3	94.2	70.4	33.7	10.4	11.2

*Low and High designations refer to models created based on the low and high estimates of the contribution of wheat in the Roman diet, 230kg and 330kg per year respectively.

Discussion

Composition of Roman Diet

The Romans primarily ate cereals and legumes, often supplemented with vegetables, cheese, or meat and covered with sauces made out of fermented fish, vinegar, honey, and various herbs and spices (Schneider, 2006: 919). While they had some refrigeration, much of their diet depended on which foods were locally and seasonally available. Meat and fish were luxuries primarily reserved for the upper and upper-middle classes, although lower class Romans sometimes obtained low-quality meat from either public sacrifices or urban cookhouses (Herz, 2006). These results are visually reflected in pyramids (Figures 1a and 1b, see Appendix), which show the relative importance and nutritional contributions of various foods to the ancient Roman diet (the most frequently consumed foods are shown at the bottom of each pyramid, while the least frequently consumed foods are shown near the top). Since meats and fish were more often eaten as luxuries than as everyday foods, the protein from pulses played a fairly significant nutritional role for the ancient Romans. Garnsey (1998) even suggests that lentils, broad beans, and chickpeas provided most of the non-cereal calories and protein for the Roman people.

While the classical texts do not clearly indicate the amount of meat commonly consumed in ancient Rome, archaeological evidence suggests

that Roman people across most socioeconomic classes consistently consumed at least a limited quantity of meat. Cucina and colleagues analyzed 77 skeletons from the Necropolis of Vallerano, a suburb of Rome and found a low frequency of oral pathologies, which they correlate with a diet that includes meat and "low-calorific" crops, but which is "seemingly low in refined carbohydrates" (Cucina *et al.*, 2006: 104). In addition, Cucina and colleagues suggest that based on the presumed social classes of these skeletons, "their diet mainly consisted of cereals and low-cost goods," while the more valuable foods (such as meat, dairy, spices, etc.) were instead reserved to sell at the nearby markets (Cucina *et al.*, 2006: 106). In conclusion, these authors suggest that the lack of oral pathologies in the skeletons examined at Vallerano is not inconsistent with a primarily vegetarian diet, as long as grains made up a lower proportion of the diet compared to other vegetable foods (Cucina *et al.*, 2006: 115).

Results from Cucina and colleagues (2006) rely on osteological data to support the supposition that populations in Roman suburbs, which primarily grew perishable crops rather than grain, would have eaten less grain than their urban and rural counterparts. Although Cucina and colleagues' (2006) osteological study provides important evidence of the nutritional profiles of one community of Roman people, their results cannot be generalized to explain Roman nutrition as a whole. As this pilot study attempts to quantify the nutritional properties of Roman diets in general, it relies less on specific osteological case studies and instead more on both classical literature and contemporary nutritional information. Future studies on ancient nutrition should incorporate both archaeological and osteological evidence in order to more clearly examine how the nutritional profiles of ancient Romans described in classical texts differs from those suggested by alternative lines of evidence.

In addition to the staple foodstuffs of grains, pulses, and occasionally meats, the ancient Romans also enjoyed a wide variety of fruits, vegetables, and exotic spices and condiments. While fresh fruits were probably only seasonally available in ancient Rome, Columella speaks to the important nutritional role of dried fruits (such as apples, figs, and pears) in rural people's winter diets (Columella Book 12, XIV; noted in Brothwell and Brothwell, 1998: 146). These dried fruits likely provided both essential vitamins and small amounts of sugar for the Roman people who had access to them. Contrary to Schneider's (2006: 918) assertion that Cato provided his slaves with both figs and preserved olives, Cato does not in fact mention that figs were given to his slaves. Instead, he clearly discusses providing cereals and preserved olives to his slaves (Cato

56, 58), and limits his remarks on figs to methods of cultivation, harvesting, and preserving them, rather than to their role in the diets of different members of Roman society (see esp. Cato 99, 143, 8.1, 94). Cato leaves us unsure about whether or not ancient Roman landowners provided figs for their slaves.

While fruits may have been nutritionally important to certain classes of ancient Roman people, the results of this study's classical literature review support Schneider's (2006: 918) assertion that neither wild animals nor wild plants are likely to have played large roles in the nutritional status of the ancient Romans. Cultivated tree nuts however, may have played a small but significant role in the Roman diet. This is because while they were usually only eaten as condiments or as dessert, they are exceptionally high in calories, fat, and protein, meaning that they can still affect human nutrition even when consumed in small amounts (Brothwell and Brothwell 1998: 149; USDA Nutrition Database).

A variety of sodium-filled condiments may also have had a significant impact on ancient Roman nutrition. The ancient Romans seem to have enjoyed covering their foods in complex sauces, made with many different ingredients and oftentimes possessing fairly distinct flavors. One sauce for oysters and shellfish from Apicius for example, calls for "pepper, lovage, parsley, dry mint, bay leaf, malabathrum [leaves of *Cinnamomum tamala*], plenty of cumin, honey, vinegar, and liquamen [fermented fish sauce]" (Brothwell and Brothwell 1998: 66). In general however, the main sauce enjoyed by the ancient Romans was garum, a fermented and salted fish sauce, which they applied liberally to savory and sweet dishes alike. Smriga and colleagues (2010) analyzed the nutritional properties of garum found in residues left on pots from the "Garum Shop" in Pompeii. They found that the ancient garum residue contained amino acids in amounts comparable to those found in modern Southeast Asian and southern Italian fish sauces, with free glutamate, glycine, and alanine providing most of the flavor and amino acid content of the sauce (Smriga *et al.*, 2010: 442). While the high levels of amino acids and salt in garum undeniably played an important role in Roman nutrition and digestive processes, classical texts do not clearly discuss the quantities in which garum was consumed by ancient Roman peoples, which therefore prevents us from quantifying its nutritional role in this initial study.

Nutrition

This study outlines nutritional properties of a Roman diet in which individuals maintain a continually high level of consumption of both cereals and supplementary non-cereal foods. It is unlikely however, that all (or even most) Romans had access to this wide variety of food items in such quantities at all times of year (Schneider 2006: 917). Furthermore, Garnsey (1998: 240) suggests that while most lower class Romans could expect to supplement their grains with some poor quality wine, legumes and olive oil, and even sometimes with vegetables, fish, or fish-sauce, other animal products such as meat, eggs and dairy were rarely obtainable for these people. In addition, while Table 6 includes information on the nutritional intake for both men and women, these numbers assume that men and women had access to the same dietary quality and quantities. Due to various cultural considerations and ancient medical theories however, it is likely that ancient Roman women would not have eaten as much food as men on a daily basis. Finally, this study does not take longevity into consideration as a factor in and byproduct of ancient nutritional intake. Neither lifespan nor differences in nutritional intake across the various phases of life are indicated in the classical texts, and thus the relationship between nutrition and longevity could not be taken into account in this study. Future studies that examine osteological evidence in conjunction with ancient literary sources may be able to better understand and examine these issues.

The high proportion of cereals and legumes in the ancient Roman diet provided them with substantial amounts of calories, protein, calcium, and iron. Because their staple foods are deficient in vitamins A, C, and D, the Romans likely obtained these nutrients from seasonally available fruits and vegetables, although spices may also have played a role in providing these nutrients. This analysis indicates that their diet was fairly low in vitamin D, sodium, and sugar. It has to be expected however, that the ancient Roman people's high sun exposure and proximity to the sea also had positive health effects, conferring both vitamin D and iodine respectively.

One unanticipated conclusion of this study is that in the quantitative model, pulses make up a much lower percentage of the ancient Roman diet than might otherwise be expected based on qualitative information from primary literary sources. This disparity may be attributable to the fact that concrete evidence regarding the actual amount of legumes consumed by the ancient Romans is largely uncertain and

unavailable. Therefore, this initial study instead relied on the known amount of legumes consumed in modern Mediterranean diets in order to calculate the nutritional role of legumes in the ancient Roman diet. This difference may have created the disparity in this study's conclusions, as legumes were likely not eaten in the same dietary proportions by both the ancient Romans and modern Mediterranean people. As quantification methods continue to be explored and improved upon in future studies, disparities such as this one seen with legumes will hopefully be more clearly resolved and understood.

Despite the aforementioned problems associated with using contemporary food consumption data as a model for ancient diets, this quantitative method of inquiry can be effectively employed to create a general model of the core nutritional profile of ancient Roman diets. The data gathered using this type of quantitative modeling should be considered only while keeping these conceptual issues in mind and carefully considering the available qualitative information regarding both ancient and contemporary diets.

Conclusions

As has been suggested by previous studies, the overall nutritional properties of the Roman diet are largely dependent on its three main components: grains, wine, and olives (or olive oil) (Schneider, 2006: 919). This study takes our prior knowledge of the three basic components in the Roman diet and broadens our analytical focus to encompass the biological and nutritional properties of all of the possible food items consumed by ancient Romans. This method has not been free of problems however, as other than quantities for the amount of grain that was given to slaves and soldiers per year, there is little quantitative data from ancient Rome on how much of a given food item people tended to consume in a given time period (Garnsey, 1998). While quantitative methods for investigating ancient nutrition may still be somewhat imprecise and rely on various estimates and assumptions about ancient food consumption, they do provide us with a useful overview and general profile of the probable nutritional and biological properties of the Roman diet as a whole.

This study found that the core constituents of the Roman diet (cereals and legumes) meet many of the daily nutritional needs of men and women when consumed in the amounts presumably eaten in ancient Rome. The Romans likely met their additional nutritional needs using a wide variety of more sporadically consumed foods such as meats, fruits,

and spices. The nutritional impacts of meat, wine, garum and other specialty food items in the Roman diet should be further explored in future studies, perhaps by incorporating additional archaeological and osteological evidence. In addition, further examining how ancient diets varied throughout the Roman Empire could perhaps lead us to better understand both the origins and spread of Mediterranean dietary traditions as well as how nutritional profiles may have varied throughout the empire.

This investigation also found that neither the nutritional properties nor the frequency of consumption for a given food seem to have been the determining factor for how often it was mentioned by classical authors. This initial finding of a lack of correlation between these variables is intriguing and warrants further investigation into uncovering why the ancient Roman authors mentioned different food items in such varying frequencies.

Although we may never be able to know exactly what the ancient Romans ate, we should continue to attempt to quantify and better reconstruct the nutritional properties and composition of their diet through further investigations. This initial study provides one model for introducing such quantification methods into research on ancient diets.

References

André, Jacques. *Apicius, L'art culinaire*. Texte établi, traduit et commenté - (Collection des Universités de France). Paris: Les Belles Lettres, 1987.

André, Jacques. *L'alimentation et la cuisine à Rome.* Paris: Les Belles Lettres, 1981.

André, Jacques. *Le noms de plantes dans la Rome antique.* Paris: Les Belles Lettres, 1985.

Briggs, W.W. Jr. *Concordantia in Varronis Libros De Re Rustica.* Hildesheim: Georg Olms Verlag, 1983.

Brothwell, Don and Patricia Brothwell. *Food in Antiquity: A Survey of the Diet of Early Peoples*. Expanded edition. Baltimore: Johns Hopkins University Press, 1998.

Confederation of the food and drink industries of the EU (CIAA). Guideline Daily Amounts (GDAs) – GDAs Explained, 2010. http://gda.ciaa.eu/asp2/gdas_portions_rationale.asp?doc_id=127.

Couplan, Francois and Eva Styner. *Guide des plantes sauvages comestibles et toxiques.* Paris: Delachaux et Niestlé, 1994.

Cucina, Andrea, Rita Vargiu, Domenico Mancinelli, R. Ricci, Elena Santandrea, Paola Catalano, and Alfredo Coppa. "The Necropolis of Vallerano (Rome, 2nd – 3rd Century AD): An Anthropological Perspective on the Ancient Romans in the *Suburbium*. in *International Journal of Osteoarchaeology* 16: 104-117, 2006.

Dalby, Andrew. *Food in the Ancient World: From A to Z.* London: Routledge, 2003.

Dioscorides, Pedanius. *De materia medica*. Translated by Lily Y. Beck. Hildesheim: Olms – Weidmann, 2005.

Food and Agriculture Organization of the United Nations (FAO). FAOSTAT Food Balance Sheets (Italy, Turkey, Greece, and Spain). http://faostat.fao.org/site/368/default.aspx#ancor.

Foxhall, Lin and Forbes, Hamish A. "Sitometreia: the role of grain as a staple food in classical antiquity." in *Chiron* 12: 41-90, 1982.

Garnsey, Peter. *Cities, Peasants and Food in Classical Antiquity: Essays in Social and Economic History*. Walter Scheidel, ed. Cambridge: Cambridge University Press, 1998.

Herz, Peter. "Meat, consumption of," in Hubert Cancik and Helmuth Schneider (eds.), *Brill's New Pauly. Encyclopedia of the Ancient World*, vol. 8. Leiden and Boston: Brill, 2006, cols. 535-537.

Hooper, William Davis. *Marcus Porcius Cato, On Agriculture. Marcus Terentius Varro, On Agriculture*. With an English Translation.

Revised by Harrison Boyd Ash (Loeb Classical Library 283). Cambridge MA: Harvard University Press, and London: William Heinemann, 1934.

Jashemski, Wilhelmina and Frederick Meyer eds. T*he Natural History of Pompeii.* Cambridge: Cambridge University Press, 2002.

Keys, Ancel. Coronary heart disease in seven countries. *Circulation* 41 (suppl. 1): 1-211, 1970.

Paolucci, Paula. *Anthimi epistulae de observatione ciborum ad Theodoricum regem Francorum Concordantiae.* Hildesheim: Olms – Weidmann, 2003.

Pearson, Kathy. "Nutrition and the Early-Medieval Diet." in *Speculum* 72(1): 1-32, 1997.

Pignatti, Sandro. *Flora d'Italia*. Bologna: Edagricole, 1982.

Rackham, Harris, William Henry Samuel Jones, and David Eichholz, Pliny, *Natural History*, with an English Translation 10 vols. (Loeb Classical Library 330, 352-353, 370-371, 392-394. 418-419). Cambridge MA and London: Harvard University Press, 1938-1962.

Rodgers, Robert Howard. *Columellae res rustica, Incerti auctoris, Liber de arboribus*. Recognovit brevique adnotatione critica instruxit - (Scriptorum classicorum bibliotheca Oxoniensis). Oxonii: E Typographeo Clarendoniano, 2010.

Rodgers, Robert Howard. *Palladius, Opus agriculturae, de veterinaria medicina, de insitione*. Edidit - (Bibliotheca Scriptorum Graecorum et Latinorum Teubneriana). Leipzig: B. G. Teubner, 1975.

Schneider, Helmuth. "Nutrition," in Hubert Cancik and Helmuth Schneider (eds.), *Brill's New Pauly. Encyclopedia of the Ancient World*, vol. 9. Leiden and Boston: Brill, 2006. cols. 914-921.

Smriga, Miro, Toshimi Mizukoshi, Daigo Iwahata, Sachise Eto, Hiroshi Miyano, Takeshi Kimura, Robert I. Curtis. "Amino acids and minerals in ancient remnants of fish sauce (garum) sampled in the "Garum Shop" in Pompeii, Italy." in *Journal of Food Composition and Analysis* 23: 442-446, 2010.

Striegan-Keuntje, Ilona. *Concordantia et Index in Apicium*. Hildesheim: Olms-Weidmann, 1992.

Thompson, D'Arcy Wentworth. *A Glossary of Greek Fishes.* London: Oxford University Press, 1947.

Touwaide, Alain. *Medicinal Plants of Antiquity*. Unpublished computerized database.

Toynbee, Jocelyn M.C. *Animals in Roman Life and Art.* Ithaca, New York: Cornell University Press, 1973.

Tutin, Thomas Gaskell, Vernon Hilton Heywood, Norman Alan Burges, David M. Moore, David Henriques Valentine, Stuart Max Walters, and David Allardice Webb. *Flora Europaea.* Cambridge: Cambridge University Press, 1980.

USDA Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference. http://www.nal.usda.gov/fnic/foodcomp/search/.

Van Wyk, Ben-Erik. *Food plants of the world: an illustrated guide.* Portland, Oregon: Timber Press, 2005.

Varro, Marcus Terentius. *On Agriculture, with an English translation by William Davis Hooper, revised by Harrison Boyd Ash,* [Loeb Classical Library No. 283] Cambridge MA: Harvard University Press, 1935, pp. 159-529.

World Health Organization (WHO) and FAO. Vitamin and mineral requirements in human nutrition: Second edition, 2004. http://whqlibdoc.who.int/publications/2004/9241546123.pdf.

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Appendix:

Figure 1a: Suggested Relative Role of Foods in Roman Diet by Food Category

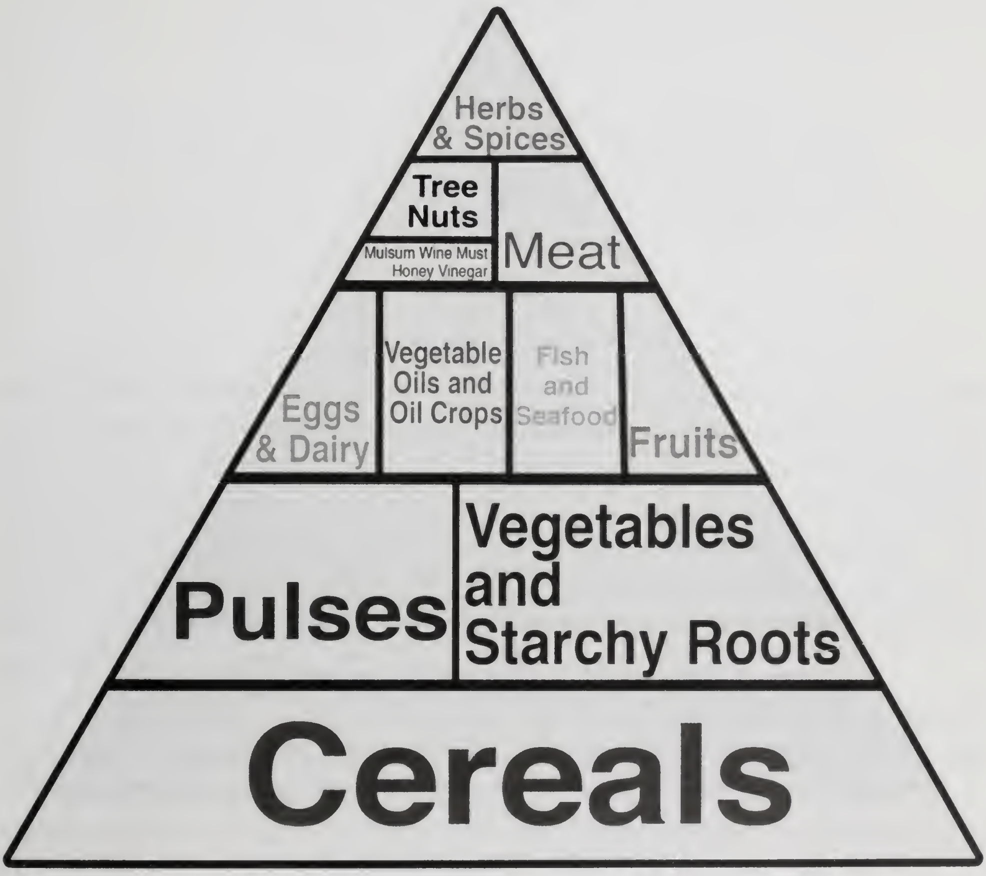
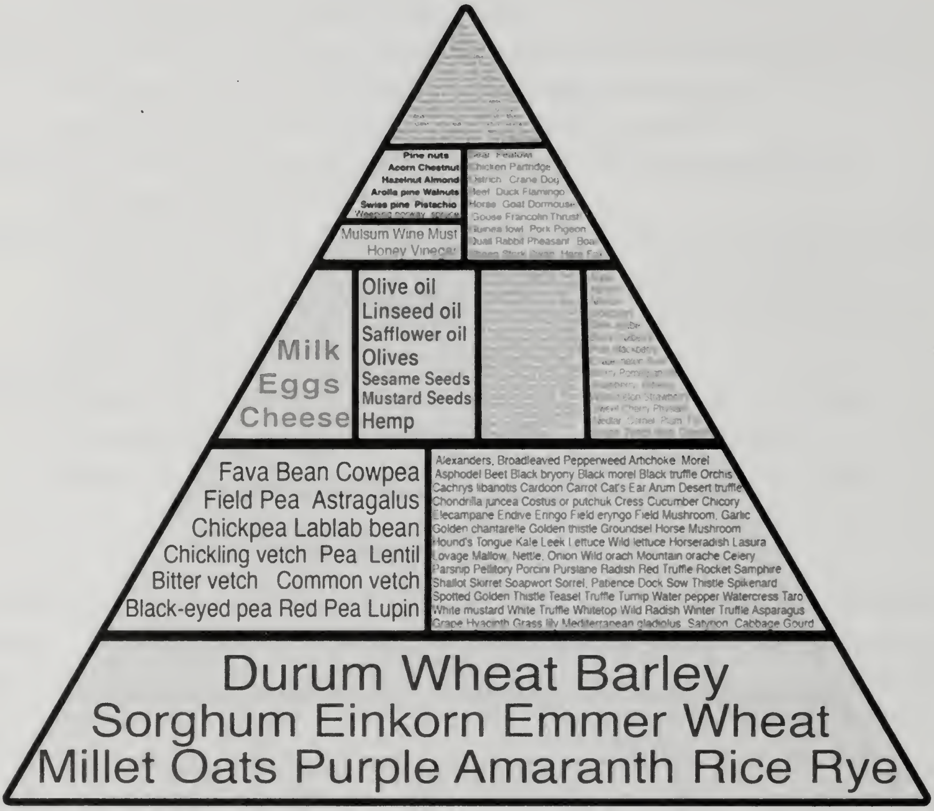


Figure 1b: Suggested Relative Role of Foods in Roman Diet by Name



The Cosmic Microwave Background Songs in the Universe

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Abstract

The Cosmic Microwave Background gives astronomers a lot of information about our early universe and explains why it has structure. Yet the details are a bit esoteric. Reviewed here are the basic concepts and discoveries of the Cosmic Microwave Background from an astronomer's point of view.

Introduction

The Cosmic Microwave Background (CMB) is a hot (so to speak) topic in astronomy. Sometimes called 'wrinkles in space-time', the CMB tells us about the birth and evolution of the universe we see. It maps the earliest moments of our universe. Recent CMB experiments have firmly established the Big Bang Model as the leading theory in cosmology. Yet, despite its fascination, the CMB can be tricky to decode. So let us look at some concepts that will help us understand these experiments and what they tell us.

We call the electromagnetic radiation that still lingers from the very early universe the *cosmic microwave background* radiation – *cosmic* for its origin in the very early universe, *microwave* because it shows up in the microwave section (1.9 mm) of the electromagnetic spectrum, and *background* because it fills all of space.

Several people had predicted the existence of the CMB as early as the 1940s. In 1941 the chemist Gerhard Herzberg almost discovered it in a stellar spectrum. The CMB's serendipitous discovery in 1964 by radio astronomers Arno Penzias and Robert Wilson earned them the 1978 Nobel Prize. They were using a radio telescope (antenna) to scan for signals bouncing off echo balloon satellites. They went to great lengths to track down a ubiquitous 1.9 mm 'noise' in their data. They even removed the "white dielectric material" left in the antenna horn by nesting pigeons. They also removed the pigeons.

These CMB photons are all around us. They are so weak, however, that it takes very sensitive microwave detectors to detect and measure

them. Optical telescopes will not do the job. The space between stars and galaxies (the *background*) is dark to an optical telescope. But a sufficiently sensitive radio telescope shows a faint background glow, almost exactly the same in all directions, that is not associated with any star, galaxy, or other object. This glow is strongest in the microwave region of the radio spectrum (that 1.9 mm wavelength).

The CMB fills the universe and can be detected everywhere we look. In fact, if we could see microwaves, the entire sky would glow with a brightness that is astonishingly uniform in every direction. The temperature (associated with the peak in the energy distribution at 1.9 mm)[i] of this background is uniform to better than one part in a hundred thousand (*i.e.*, the temperature variation on different angular patches of the sky is less than 1 part in 100,000). This uniformity is one compelling reason to interpret the radiation as remnant heat from the Big Bang; it is very difficult to imagine a local source of radiation that is this uniform.

A *perfectly* uniform background distribution will not explain why our universe looks the way it does. The universe contains clumps of matter of all sizes from atoms to galaxies. Such rich structure could not form from a perfectly smooth background. We need to have some wrinkles in the otherwise smooth background. If we have small wrinkles (bumps, ripples) or hills and valleys early in the universe, matter will tend to fall into the valleys, eventually producing dense regions that become the sites of galaxies. Matter attracts matter, so these 'valleys' get denser, eventually coalescing into galaxies and clusters of galaxies. Figure 1 (an idealization) indicates the concept.

Figure 1. The top figure shows conceptual hills and valleys. The bottom figure shows the top view of the same thing where the grey scale coding refers to the density of matter (dark regions have more matter, light regions less).

As we look at results from CMB experiments, then, we will expect to see the observed smooth distribution and hope for some tiny amount of rippling that will resemble the bottom of Figure 1.

To interpret these CMB experiments properly, we need to look at the origin of the CMB. The action begins at the very early universe. The Big Bang Model predicts (trust me on this – the actual theory is really messy) that the CMB originates from a time just a mere 380,000 years after the Big Bang.[ii] Let us just say that everything starts with the Big Bang (of course). The vast majority of astronomers use the Big Bang Model to describe the origin and evolution of our universe. To learn how the CMB came to be, we, like the astronomers, need to start with the Big Bang.

The Big Bang

The Big Bang Model rests on two theoretical pillars:

1. *The General Theory of Relativity*. In 1916 Einstein proposed his General Theory of Relativity (GTR) as a new theory of gravity. Gravity became, not the gravitational field of Isaac Newton, but a distortion of space and time itself. Physicist John Wheeler put it well when he said "Matter tells space how to warp, and warped space tells matter how to move."[iii] The theory continues to pass a series of ever more rigorous tests.

2. *The Cosmological Principle*. We assume matter in the universe is *homogeneous* and *isotropic* when averaged over very large scales. This assumption is called the Cosmological Principle. It is the simplest assumption to make – that if you viewed the contents of the universe with sufficiently poor vision, they will appear roughly the same everywhere and in every direction. A homogeneous universe contains the same stuff regardless in which direction you look. It is well mixed (aka homogenized milk). The physical conditions are the same at every place. An isotropic universe looks the same regardless of which direction you look. You cannot distinguish one direction from another. If the universe looks flat over there then it must look flat over here. This assumption is tested continuously as we observe the distribution of galaxies on ever larger scales.

When we look at the universe with galaxy sized eyes we see a clumpy universe with galaxies scattered about and clustered into groups. On smaller scales we see individual stars, some that cluster into groups,

and some that stand alone. And, of course, on even smaller scales we see individual people. It is only when we look at the universe as a total system that we can assume homogeneity and isotropy.

After the introduction of GTR a number of scientists, including Einstein, applied the new gravitational dynamics to the universe as a whole. In 1927 Georges Lemaître used GTR to develop the Big Bang Model. This model predicts that the universe, originally in an extremely hot and dense state, has since cooled by expanding to the present diluted state, and continues to expand today. Two years later Edwin Hubble made one of the profound observations of the early 20th century – the universe is expanding – supporting the Big Bang prediction of an expanding universe.[iv] To interpret the expansion properly requires an assumption about how the matter in the universe is distributed, hence the cosmological principle. The cosmological principle and GTR form the basis for Big Bang cosmology and lead to very specific predictions for observable properties of the universe.

For example, given the assumption that the matter in the universe is homogeneous and isotropic it can be shown (again, trust me) that the corresponding distortion of space-time (due to the gravitational effects of this matter) can have one of only three forms, shown schematically in Figure 2. It can be positively curved like the surface of a ball and finite in extent; it can be negatively curved like a saddle and infinite in extent; or it can be flat and infinite in extent – our ordinary conception of space. A limitation of Figure 2 is that we can only portray the curvature of a 2-dimensional plane of an actual 3-dimensional space. Note that in a closed universe you could start a journey off in one direction and, if allowed enough time, ultimately return to your starting point; in an infinite universe, you would never return. Which form the universe adopted will await experiments.

Of course there is a problem with the cosmological principle – called the horizon problem – the puzzle that the universe looks the same on opposite sides of the sky even though there has not been enough time since the Big Bang for light (or anything else) to signal across the universe and back. Light can only travel so fast. So how do the opposite horizons "know" how to keep in step with each other, to maintain isotropy? In other words, the universe is too big for its horizons. This cosmological problem has a solution. It is called the era of inflation. We shall meet the era of inflation in the next section when we travel backward in time.

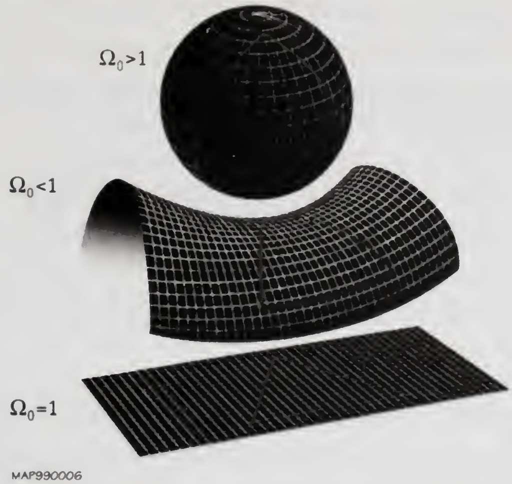

Figure 2. The top image shows a positively curved universe; the middle image a negatively curved universe; and the bottom image is a flat universe.

The Big Bang had to begin some time/where. If the universe had a beginning, when/where was it? We know the 'when'. Several ingenious astronomical experiments have measured the 'when' and they all agree with an age of about 13.7 billion years with an error about ±200 million years. Because the universe has a finite age we can only see a finite distance out into space (~13.7 billion light years). This is our *horizon*. The Big Bang Model does not attempt to describe that region of space significantly beyond our horizon, nor can optical telescopes see the horizon.

We also know the 'where' – it was everywhere. The Big Bang did *not* occur at a single point in space as an "explosion" of matter moving outward to fill an empty universe. It is better thought of as the simultaneous appearance of space everywhere in the universe. The region of space within our present horizon was indeed no bigger than a miniscule point in the far distant past; however, there is no "center of expansion" – no point from which the universe is expanding. If we picture the universe as the surface of a ball, then the radius of the ball grows as the universe expands, but all points on the surface of the ball (the universe) recede from each other in an identical fashion. The interior of the ball is not part of the universe.

By definition, the universe encompasses all of space and time as we know it, so it is beyond the realm of the Big Bang Model to postulate what the universe is expanding into. In either the open or closed universe, the only "edge" to space-time occurs at the Big Bang, so it is not logically

necessary (or sensible) to consider this question. Likewise it is beyond the realm of the Big Bang Model to say what gave rise to the Big Bang.

The question then becomes can we look far enough back to reach the origins of the CMB?

When we look out in the sky, we are actually looking backwards in time. Light from distant objects takes longer to reach us than the light from nearby objects, and thus we are observing now how they appeared in the past. The light from galaxies, however distant, permits us to see back only a few billion years, not 13.7 billion. This few billion years is our *look-back time*. There probably were no galaxies 13.7 billion years ago, so it is not surprising that galaxy light is insufficient to show us the CMB. Optical telescopes will not do the trick. We need to get creative to see that distant horizon.

If we can somehow reach the epoch of the CMB, then we can use the CMB to tell us how the universe developed to become what we see today. Let us try a trip back in time to meet the early universe, where we might detect those CMB 'wrinkles in space-time'.

Moving Backward in Spacetime in Search of the CMB

From Here-and-Now to the Epoch of Last Scattering

We start the trip with the physical conditions of the here-and-now. Our current temperature is just about three cold degrees above absolute zero. There are about 400 photons per cubic centimeter. The total mass in our observable universe is about 10^{51} kg[v] (give or take a few powers of ten) which is equivalent to about 10^{78} hydrogen atoms.[vi] That sounds like a lot until you fold in the volume. We can estimate the volume ($\propto r^3$) because we know the radius, r, and the speed of light, c.[vii] We know the radius because we have Hubble's Law which gives us H_0, the Hubble constant: $r = c/H_0$, where r is the radius of the Hubble sphere. The mass density of the universe, then, is only about 10^{-30} gm per cubic centimeter, or about one hydrogen atom per cubic meter. This means we live in a rarefied universe. Fortunately for us there are locally dense spots like our planet.

Hubble's observations showed that space itself expands with time everywhere and increases the physical distance between two co-moving points. If the universe is getting bigger now, then it had to be smaller, denser, and hotter in the past. Let's go backwards and see what we can find.

Stepping backwards in space-time we watch (from our privileged imaginary position) the universe shrink down in size and heat up in temperature. See Figure 3 for a conceptual timeline. That 10^{51} kg of matter must squeeze into ever decreasing volumes. When the visible universe decreases to half its present size, the density of matter increases until it is eight times higher and the temperature is twice as hot as it is today. Recall that when one compresses an object or a gas (or the universe), the object heats. For example, the hand operated air pump one uses to pump up a flat tire gets hotter as one uses it. The universe does the same thing as it contracts.

When the visible universe reaches one hundredth of its present size, its temperature is a hundred times hotter (273 K or 32°F, the temperature at which water freezes on the Earth's surface).

We are moving closer to the Big Bang event. When we are a mere 380,000 years away from the Big Bang the universe is about one eleven hundredth its present size. The temperature is about 3,000 K. We have arrived at the important *epoch of last scattering* or *time of recombination.*

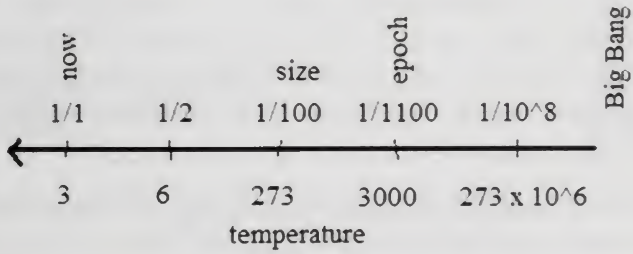

Figure 3. A conceptual timeline, time increases right to left from the Big Bang to now. The range in size appears above the timeline. The matching range in temperature in degrees Kelvin appears below the timeline.

From Time Zero to the Epoch of Last Scattering

Things now get complicated (yes, I know, but stay with me). Instead of continuing to move down in time from the epoch of last scattering, let us leap over that epoch to reach the Big Bang, turn around, and move outward in time to meet that epoch of last scattering from the other side.

We cannot discuss the Big Bang itself – we do not know the physics. So we pick up the story a mere whisper after the Big Bang (all of 10^{-32} seconds away) when the *era of inflation* has just ended. The era of inflation starts just after the Big Bang and ends 10^{-32} seconds later when the temperature has dropped to a whopping 10^{19} K. The era of inflation is

the *exponential* expansion of space-time by an enormous factor of 10^{78} in volume. Our entire observable universe originates in a small, causally connected region. Before inflation, it is small enough to "know" what happens at each horizon. Then it inflates drastically maintaining this initial knowledge. Miniscule when it began inflating, at the end of the era of inflation there is a universe that will grow to be the one we see. Inflation answers the problem I mentioned earlier. It answers the horizon problem and the origin of the large-scale structure of the cosmos. Quantum fluctuations in the microscopic inflationary region, magnified to cosmic size, become the seeds for the growth of structure in the universe. Alan Guth developed this approach in 1980.

After the era of inflation the universe continues to expand, but not exponentially. About a minute and a half after the Big Bang, there are no atoms; however, all the protons and neutrons have formed.

Continuing outward, when the visible universe is only one hundred millionth its present size, its temperature has dropped to 273 million degrees above absolute zero and the density of material is comparable to the density of air at the Earth's surface. At these high temperatures, hydrogen is completely ionized into free protons and electrons, although neutrons have combined with protons to form the deuterium and helium nuclei in a process called Big Bang nucleosynthesis. The result gives a ratio of about 12 hydrogen nuclei to 1 helium nucleus.

At this size and temperature everything is *coupled* together into a hot, opaque, dense primordial soup (plasma). This hot soup has a smooth consistency and consists of fundamental particles like electrons, protons, helium nuclei, deuterium nuclei, neutrinos, and of course, photons. The opaqueness is important. If we were there we would not 'see' anything. Radiation and matter are coupled together. There are no atoms as separate objects. What we think of as matter does not exist.

In this very hot dense soup the photons easily scatter off the free electrons. The photons are densely packed enough to respond like bouncing molecules in a gas. Thus, photons wandered through the soup of the early universe (bouncing off electrons), just as optical light wanders through a dense fog. This process of multiple scattering produces what is called a thermal or *blackbody* spectrum[viii] of photons. It essentially randomizes the photons.

The universe continues to expand and cool. Figure 4 gives a conceptual view of those earliest moments.

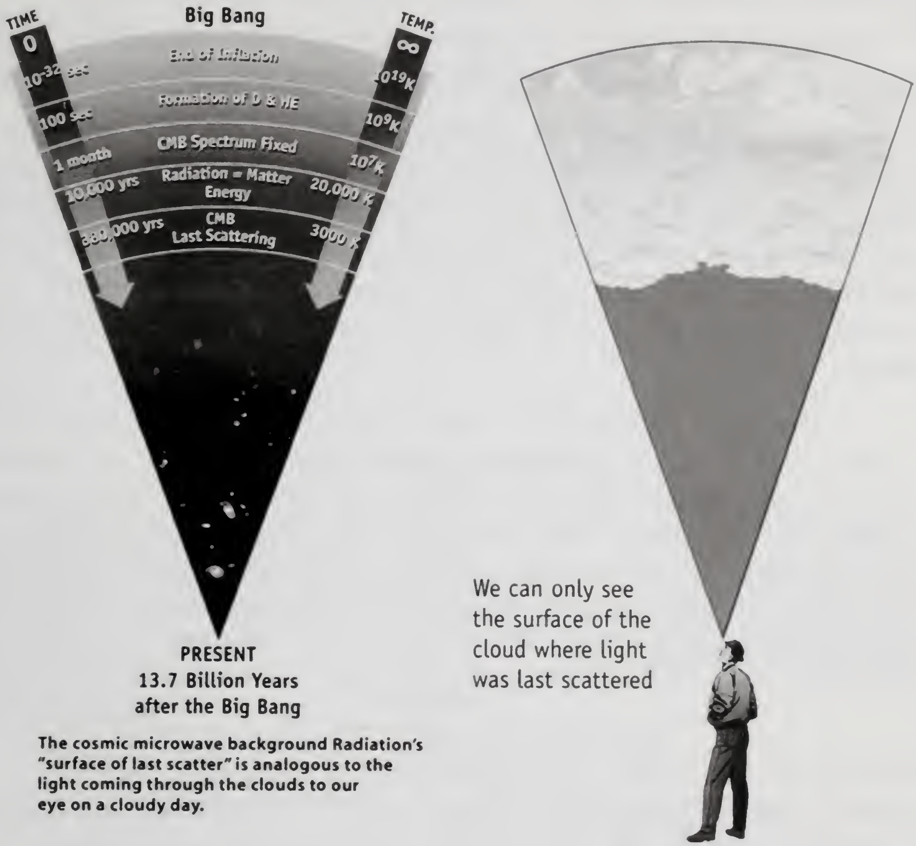

Figure 4. Two views of the universe – the left shows details of the early universe; the right shows what we can observe.

About 380,000 years after the Big Bang the temperature has fallen to around 3,000 K. It is now that the electrons and nuclei are able to combine into atoms (mostly hydrogen). Once atoms could form as separate objects, then radiation and matter could *decouple*, and radiation could move through space largely unimpeded. The soup clarifies. The universe becomes transparent. Now we can 'see'. With electrons locked up in atoms, radiation (photons) can no longer scatter off free electrons. Photons can move freely through space. We have arrived back at the epoch of last scattering. We call the radiation (those randomized photons) from this epoch the *Cosmic Microwave Background*. The CMB is a snapshot of that last scattering epoch, *i.e.* it is an image of that moment when matter and photons decoupled. This epoch is the barrier to our observations about the early universe, where the epochs behind this barrier are not accessible to us.

At The CMB

Whew! Now that we have crisscrossed the universe to find the origins of the CMB let us concentrate on the CMB itself.

Just as the universe heated as we compressed it, it will cool as it expands. As the universe expands, the temperature of the CMB photons drops; today, the CMB radiation is very cold and invisible to the naked eye. Now down to 2.725 K, the temperature will continue to fall as the universe continues to expand. For comparison, human beings radiate around 300 K (98.6° F) in the infrared – this is why infrared night goggles work.

The CMB photons kept scattering until the epoch of last scattering – clever, this is why it is called the epoch of *last* scattering. After that they move freely maintaining their thermal form through the transparent universe we see today. Thus, we expect their distribution of energy (the spectrum) to maintain its blackbody shape. Figure 5 plots CMB frequency (wavelength) versus CMB intensity. It matches rather well to the theoretical blackbody curve.

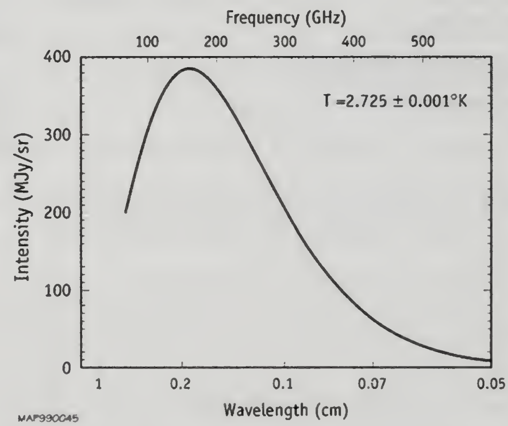

Figure 5. The spectrum of the CMB - This is what the blackbody curve looks like at the temperature (2.725 K) of the CMB, thus the spectrum peaks in the microwave range frequency of 160.2 GHz, corresponding to a 1.9 mm wavelength.

To study the CMB astronomers will look through much of the universe (as if it were clear air) back to when it becomes opaque: a view back to 380,000 years after the Big Bang. This is the "wall of light" or the epoch of last scattering. Maps of the temperature of the CMB are maps of this surface of last scattering, and astronomers hope to see the collection of spots (wrinkles) in space at which the decoupling (recombination) occurred.

Recall that the universe 'cleared' when hydrogen atoms first formed. This is usually called "time of recombination." Thus the temperature of the CMB at any given spot on the sky is a relic of this time.

During the 1960s the interpretation of the CMB was controversial. Some proponents of the steady state theory of the universe (no Big Bang) argued that the microwave background was the result of scattered starlight from distant galaxies. However, during the 1970s the consensus grew that the CMB was a remnant of the Big Bang. This was largely because measurements at a range of frequencies showed that the spectrum was probably a thermal, blackbody spectrum, a result that the steady state model was unable to reproduce. It was time for a real experiment.

The Cosmic Background Explorer

Many astronomers predicted the blackbody spectrum and the wrinkles (anisotropies) in the CMB, but it took the work of two astronomers, George Smoot and John Mather, to clinch the issue. They designed and launched the satellite called the Cosmic Background Explorer (COBE) to study the CMB. They received the 2006 Nobel Prize for their efforts.

COBE[ix] was launched November 18, 1989 and carried three instruments, one to search for the cosmic infrared background radiation, one to map the cosmic radiation sensitively, and one to compare the spectrum of the cosmic microwave background radiation with a precise blackbody. Launched into a near-Earth orbit, the satellite had an altitude of 900 km, making 14 orbits per day.

COBE showed that the CMB spectrum is that of a nearly perfect blackbody with a temperature of 2.725 ± 0.002 K. COBE measured the spectrum at 34 equally spaced points along the blackbody curve. The error bars on the data points are so small that they cannot be seen under the predicted curve in the figure (Figure 5)! The CMB spectrum by the COBE satellite is the most precisely measured blackbody spectrum in nature. When the COBE team presented their results at a 1992 meeting of the American Astronomical Society they received a rare standing ovation. Even Steven Hawking gave it a rave review in 1992 when he said it was the discovery of the century if not of all time.[x]

As good a match as it was, an *exact* match to the curve would be worrisome because if the background radiation is absolutely smooth, then how do we get galaxies to form? We need wrinkles, a tiny anisotropy, in

the smooth background to form the condensations of matter (seeds) from which galaxies could grow – those hills and valleys of Figure 1.

Fortunately, COBE also showed that the CMB has a tiny intrinsic anisotropy (ripples) at a level of one part in 100,000: the rms temperature variations are only 18 μK or put another way: $\delta T / T \approx 10^{-5}$ where T is temperature. This means the CMB is not perfectly isotropic; it has ripples (wrinkles). It is in these ripples that the structures we see today will form.

How did the COBE team find the miniscule ripples in their data? It took work. They had to remove interfering ripples in the data before the very small remaining variations could be seen. One rather large interfering wrinkle is the *dipole anisotropy* (discovered in 1969). The CMB appears slightly warmer in the direction of one's movement than in the opposite direction. Photons arriving from the direction of motion are boosted in energy; those from behind lose energy. Known as the great cosine in the sky, the dipole anisotropy is the motion of the Earth relative to the CMB, measured as the 24 hour anisotropy in the background. The relative velocity of the Earth will result in a temperature distribution across the sky:

$$T(\theta) = T_0\left(1 - \frac{v}{c}\cos\theta\right),$$

hence the term 'great cosine'. T is temperature, v is velocity, c is the speed of light, and θ is the angle of view across the sky. COBE finally pinned this down to the 6σ level and determined that our local group of galaxies (the galaxy cluster that includes our Milky Way[xi]) appears to move relative to the CMB at 627 ± 22 km/s towards the constellation of Virgo.

Why the motion? A proposed answer is that it is due to the gravitational pull of a "Great Attractor" (a source of gravitational pull) that was postulated to explain our motion. A search was started, and eventually it was found that such large clumps of matter as the hypothesized Great Attractor are found regularly through the universe. It is now believed that by summing over the mass in our Milky Way neighborhood (within a 100 million light years) one finds the net unbalanced attraction that explains our motion. The CMB is then the standard frame of reference for cosmology work.

Astronomers illustrate the CMB using a special type of map – an equal-area Mollweide projection. To understand these maps first consider how the Earth appears in this projection (Figure 6). We can see the

continents and oceans seen looking down from above. Astronomers use the same type of projection of the sky only looking up instead of down.

Figure 6. A map showing the Earth spread out in an equal-area Mollweide projection.

Figure 7 shows three data cuts from COBE. The maps show the entire sky as seen in Galactic coordinates (similar to looking at the Earth from above in Figure 7 only we are looking out towards the sky). The orientation of the maps is such that the plane of the Milky Way runs horizontally across the center of each image. The Milky Way appears as a thin strip. The top map shows all of the data – it looks very smooth. Hidden in these data are very small variations. The middle map shows the dipole anisotropy – what is left after the smooth part is removed. The bottom map shows what is left after the top and middle pieces are removed. The grey streak through the equator of the bottom map is the Milky Way signal.

There are two sources for the remaining ripples seen in the bottom map of Figure 7: (1) Emission from the Milky Way (not the CMB) dominates the equator of the map but is quite small at areas away from the equator. We understand this and need to remove it. (2) Ripples in the CMB from the edge of the visible universe dominate the regions away from the equator. We need to keep this source because this is what we are looking for. When all the interfering items are removed one gets Figure 8.

There is also residual noise in the maps from the satellite instruments themselves, but this noise is quite small compared to the signals in these maps. To get a glimpse of the errors, consider what the Earth looks like when COBE's instrumental errors are added to Figure 6 to produce Figure 9. The underlying continental structure can still be seen.

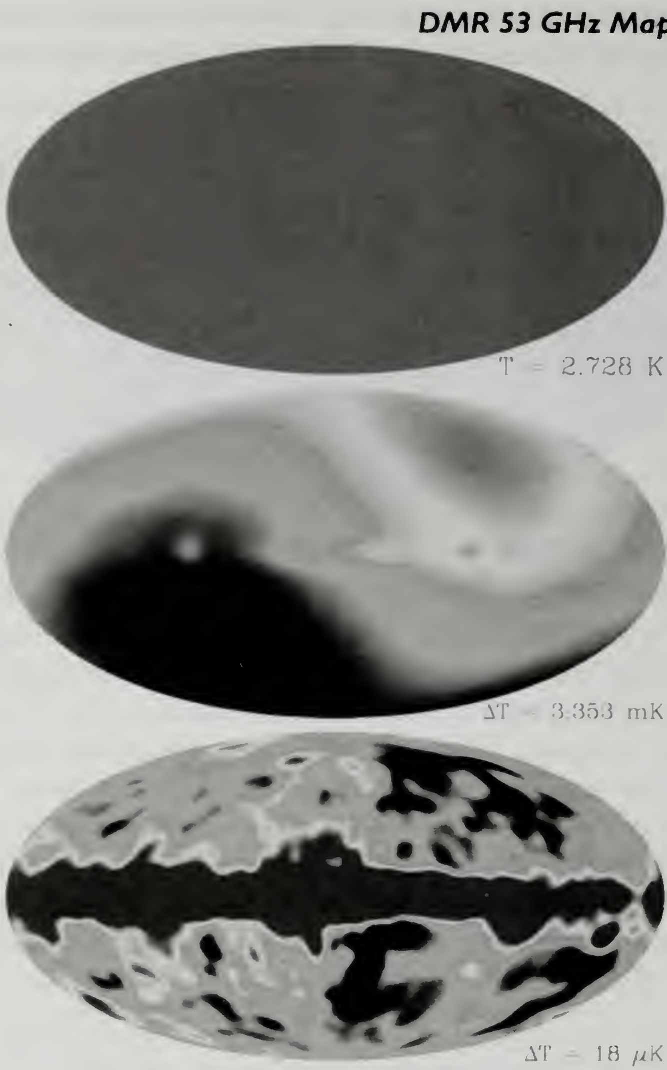

Figure 7. The top image shows the temperature of the microwave sky in a scale in which grey represents the completely uniform temperature on this scale. The actual temperature of the cosmic microwave background is 2.725 Kelvin. The middle image shows the same map displayed in a scale such that dark patches correspond to 2.721 Kelvin and light patches to 2.729 Kelvin. The "yin-yang" pattern is the dipole anisotropy that results from the motion of the Sun relative to the rest frame of the CMB. The bottom image shows the microwave sky after the dipole anisotropy has been subtracted from the map. This removal eliminates most of the fluctuations in the map: the ones that remain are thirty times smaller. On this map, the hot regions, shown in light patches, are 0.0002 Kelvin hotter than the cold regions, shown in dark patches. The grey streak through the middle represents the Milky Way.

Figure 8. Following subtraction of the dipole anisotropy and components of the detected emission arising from dust (thermal emission), hot gas (free-free emission), and charged particles interacting with magnetic fields (synchrotron emission) in the Milky Way, the CMB anisotropy can be seen as a mottling (rippling) in the COBE data.

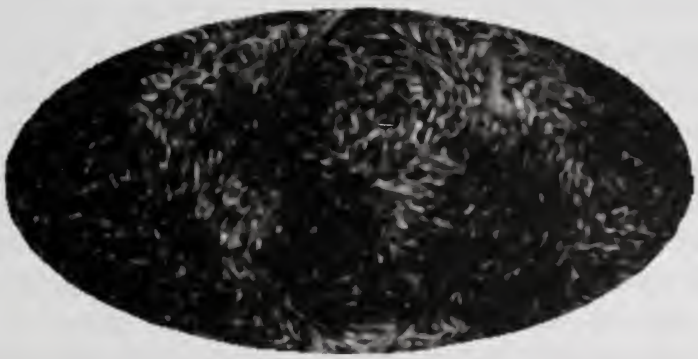

Figure 9. We can faintly see the outlines of the continents of Figure 6 underneath the added noise.

You can see what a complex data reduction process the COBE team had to use. The detailed analysis of CMB data to produce maps, an angular power spectrum, and ultimately cosmological parameters, is a complicated, computationally difficult problem. The COBE team did not release their data until they had finished many months of intensive error analyses.

After COBE

Astronomers divide the sky into angular degrees, so that 90° is the distance from the observer's horizon to the zenith. COBE, with its slightly fuzzy vision, measured temperature ripples in the 10° to 90° range, which means COBE could measure no smaller than the equivalent of an angular distance twice the distance from the Earth to the Sun. Those hills and valleys (Figure 1) of the universe are shallow but quite large. COBE was not able to resolve spots as small as clusters or even superclusters of galaxies. Hence COBE saw the *initial* conditions of the universe. Maps such as that shown in Figure 8 are amazing pictures of the early universe.

The small CMB temperature fluctuations trace real wrinkles in the density of matter in the early universe as they were imprinted shortly after the Big Bang. Thus, they can reveal a great deal about the early universe, the origin of galaxies, and large scale structure in the universe.

Of course, once astronomers had the COBE data, they wanted to see more and finer detail. Astronomers today are interested in small scale fluctuations; *i.e.*, they need to find the one degree sized wrinkles in which seeds gather to grow structure. To do this astronomers add another type of representation to measure these tiny wrinkles, one analogous to sound.

The Sound of Wrinkles

What astronomers detect on angular scales (the wrinkles) is actually 'sound'. Photons, if they are packed densely enough (as they are in the plasma of the early universe – that hot primordial soup), can behave as a gas just as air molecules do. Ordinary sound waves are just travelling compressions and rarefactions of the air which we hear as sound as they strike our ear drum (Figure 10). The hot photons of the early universe carry their version of sound waves due to gravity acting to compress the photon[xii] gas and radiation pressure[xiii] acting to resist it. This *battle* between compression and rarefaction produces acoustical ringing (like the ding-dong of a struck bell). The reason why we see it rather than hear it is that when we compress the photon gas it becomes hotter (that air pump thing). We see the photon sound waves as hot and cold spots on the sky – ripples in the universe. The theory of inflation predicts that there should be as many hot spots as cold spots. These are conceptually the bottom figure in Figure 1. What sets off the battle? It is seeded by random quantum fluctuations from the very beginning of the Big Bang.

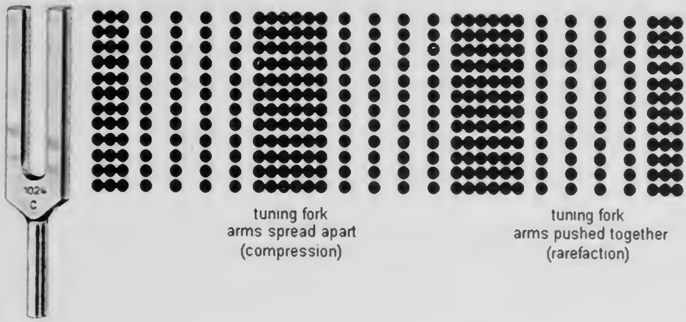

Figure 10. Sound from a tuning fork showing compression (hot spot) and rarefaction (cool spot) of air molecules

Actually, this is not the kind of sound wave we hear on Earth. The CMB wavelength is very long, on the order of 1 to 1000 mega-parsecs, and its medium is not the air but hot plasma with a mixture of photons and other elementary particles. One parsec is a distance equal to $3.08568025 \times 10^{13}$ km, so the wavelength is v-e-r-y long.

The patches in Figure 8 are due to this acoustical ringing, the size of the patch measured in angles. As I said, COBE's patches are in the 10° to 90° range.

In music, the pattern of overtones (ringing) helps us distinguish one instrument from another; it is a kind of signature of the instrument that makes the sound. In the same way, the pattern of overtones in the sound spectrum of the CMB ripples follows a pure harmonic series with frequency ratios of 1:2:3. Astronomers expect to see a series of acoustic peaks (overtones) on top of the smooth CMB spectrum. If astronomers can compare the CMB oscillations with the distribution of galaxies at different stages of the universe's history, they can measure the rate of the expansion of the universe.

The First Overtone Peak of the CMB

Many ground based and balloon experiments have now measured the CMB on the one degree scale. What CMB experimentalists do is take a power spectrum of the temperature maps (Figure 8), much as one would if one wanted to measure background noise. In essence, they take the temperature of angular patches of the universe. The peaks of the acoustic oscillations represent regions that were slightly denser than the rest of the universe.

The details (which you can ignore and skip to the next paragraph if you choose) are that they use a spherical harmonic expansion of the CMB sky where T is temperature and Y are the usual spherical harmonics:

$$T(\theta,\phi) = \sum_{l=0}^{l=\infty} \sum_{m=-l}^{l} a_{lm} Y_l^m(\theta,\phi) .$$

For a given signal, a power spectrum gives a plot of the portion of a signal's power (energy per unit time) falling within given frequency bins. Essentially, the power spectrum is a plot of the amount of temperature fluctuation against the angular size. The fluctuation is the difference in the two temperature measurements at the corresponding points. The angular wavenumber, called a multipole ℓ, of the power spectrum is related to the inverse of the angular scale.

The overtone value ℓ = 100 (the ℓ of the above equation) corresponds to approximately one degree on the sky. Recent experiments (Figure 11) have shown that the overtone power spectrum exhibits a sharp peak of exactly the right form to be the ringing or acoustic phenomena long awaited by cosmologists. The section in the Figure 11 marked 'initial conditions' represents the smooth blackbody curve. Then at ℓ = 100 the first peak appears where it was expected.

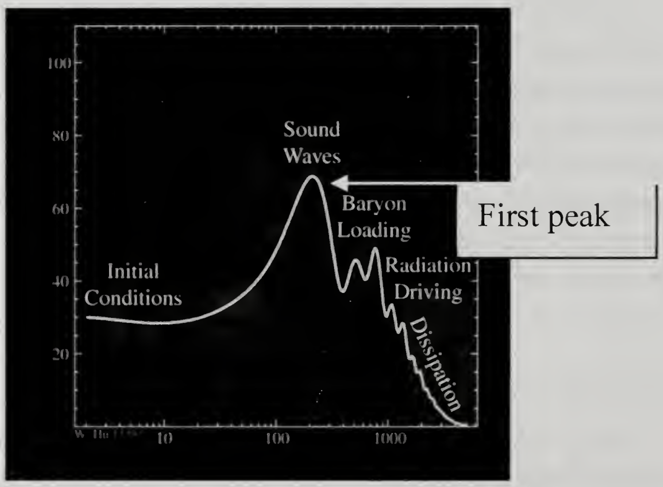

Figure 11. The multipole expansion of the wrinkles in the early universe. ℓ runs along the logarithmic x axis, and ΔT in μK runs along the y axis. The first peak is indicated by the arrow. There are faint error bars from the various experiments.

The rich structure in the plot after the initial conditions is the direct consequence of the acoustic oscillation driven by repulsive radiation pressure and attractive gravity (that battle I mentioned). The main peak is the oscillatory mode that went through 1/4 of a period (reaching maximal

compression) at the time of recombination (when electrons and protons formed neutral atoms). The lower peaks correspond to the harmonic series of the main peak frequency (those ringing overtones). An additional effect comes from geometrical projection such that the angular position of the peaks is sensitive to the spatial curvature of the universe.

A series of ground and balloon-based experiments have measured CMB anisotropies on smaller angular scales. The primary goal of these experiments was to measure the scale of the first acoustic peak, which COBE did not have sufficient resolution to resolve. The first peak in the anisotropy was tentatively detected by the Toco experiment (a balloon that flew in 1996), and the result was confirmed by the BOOMERanG and MAXIMA balloon experiments. BOOMERanG[xiv] (Figure 12) flew out of the South Pole at an altitude of 42,000 meters. Its last flight was in 2003.

Figure 12. BOOMERanG ready for launch

When I first saw the BOOMERanG results from 1998 my jaw dropped as I realized I was looking at actual spatial fluctuations in the early universe. I could see ripples ringing across time. These measurements demonstrated that the geometry of the universe is approximately flat, rather than curved. They ruled out cosmic strings as a major component of cosmic structure formation and suggested the era inflation was the right theory of structure formation.

Two of the greatest successes of the Big Bang theory are its prediction of its almost perfect blackbody spectrum and its detailed prediction of the anisotropies in the cosmic microwave background. The recent Wilkinson Microwave Anisotropy Probe (WMAP – another

satellite) has precisely measured these anisotropies over the whole sky down to angular scales of 0.2 degrees. Launched 30 June 2001 into a distant orbit, the WMAP satellite ended science observations on 20 August 2010. Figure 13 shows the total of WMAP data after all known effects are removed.

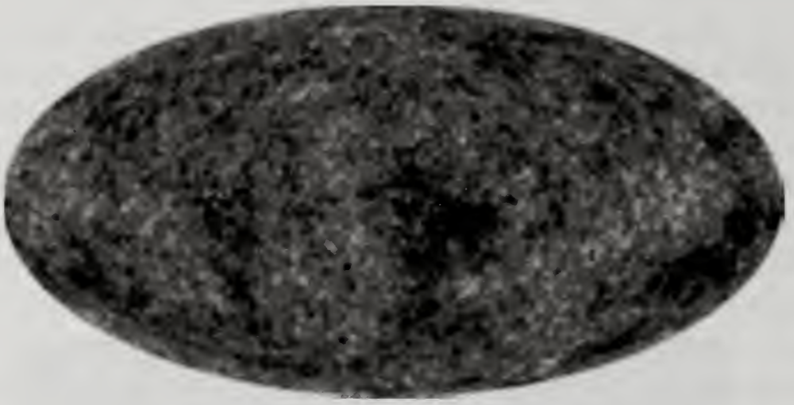

Figure 13. 7 years of CMB data from WMAP – the rippling (hot and cold spots) is clear.

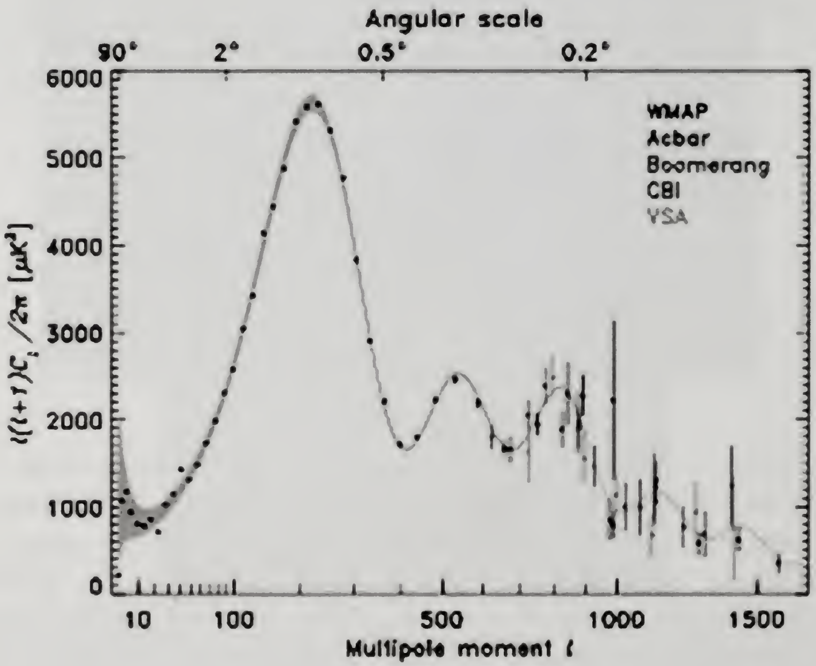

Figure 14. Acoustical data from several experiments – The power spectrum of the cosmic microwave background radiation temperature anisotropy in terms of the angular scale (or multipole moment). The data shown come from the WMAP (2006), Acbar (2004) Boomerang (2005), CBI (2004), and VSA (2004) instruments. Also shown is a theoretical model (solid line).

And More Overtones Ring In

The second acoustical peak was tentatively detected by several experiments before being definitively detected by WMAP, which has also tentatively detected the third peak. As of 2010, several experiments to improve measurements of the polarization and the microwave background on small angular scales are ongoing. These include DASI, QUaD, Planck spacecraft, Atacama Cosmology Telescope, South Pole Telescope, and the QUIET telescope. Figure 14 shows the acoustical spectrum from many experiments. The primary peak is definitive. The secondary peak is clear. The errors increase for the third peak.

The Future

Where do we go from here? Peak by peak the experiments beat down the errors. Part of this is due to improvements in the techniques for such calculations that make them much easier, and part has been motivated by a desire to know how experiments will complement each other. No one experiment is equally sensitive to all cosmological parameters[xv], and that there are combinations of certain parameters that will yield statistically identical observations for a given experiment. This is known as parameter degeneracy.

To leave you with a taste of what is coming – in the case of the CMB, there is a tremendous degeneracy between matter and the cosmological constant, Λ (what is left over after we account for all the matter in the universe). The position of the first acoustic peak in the CMB power spectrum is sensitive to their sum, but doesn't tell us much about either one independent of the other. Fortunately, there are other experiments that don't share this degeneracy (*e.g.*, high redshift supernovae). This degeneracy can also be broken by looking at the gravitational lensing of the CMB.

Gravitational lensing is what happens when the signal from some object (or CMB) encounters a lot of matter between it and you, the observer. The signal is *lensed* by the gravitational effects of the intervening matter just as the outside world is lensed by the plastic in your eyeglasses. However, as opposed to glasses, gravity lenses can produce multiple images. Figure 15 shows the effects of a real gravity lens.

Since the CMB photons that are coming to us from the epoch of last scattering have to travel through all manner of intervening matter to get to us, we would expect that there is going to be some lensing. We are

going to be looking for distortions in the CMB power spectrum that would be indicative of lensing. This is a tiny effect, however, only a 3% (10 μK) effect on the main acoustic peaks. If we can detect it, then we can gather information on the large scale structure of the universe and gather clues to the current cosmological enigma – dark energy. Dark energy is that hypothetical energy that fills the universe and tends to increase the rate of expansion of the universe.

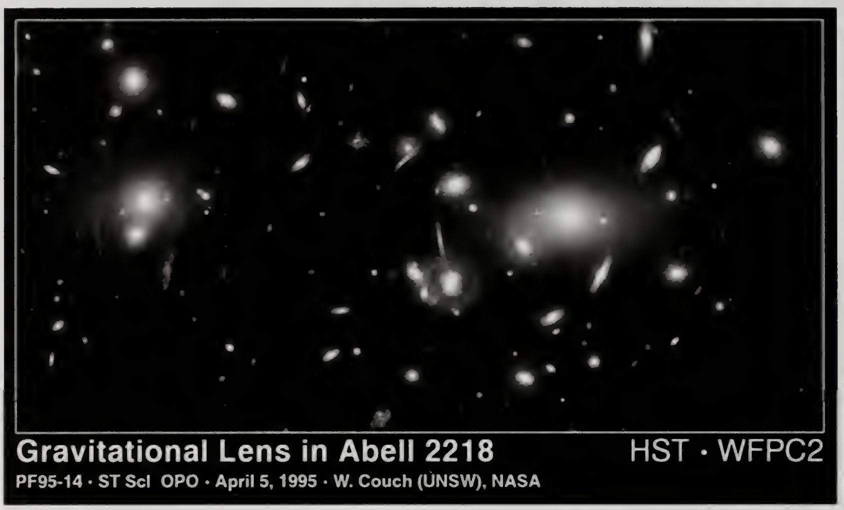

Figure 15. A gravitational lens – the arc like structures are the images of the very distant source. It is distorted by the matter between you and it.

In the meantime, people are actively measuring the *Sunyaev–Zel'dovich effect*[xvi] (abbreviated as the SZ effect), which is the result of high energy electrons distorting the CMB spectrum (in which the low energy CMB photons receive energy boosts during collision with the high energy electrons). When a CMB photon interacts with hot gas in a galaxy cluster it experiences a slight increase in energy. The SZ effect causes a change in the apparent brightness of the CMB radiation when looking towards a cluster of galaxies or any other reservoir of hot plasma. Inverse Compton scattering by the hot gas will boost the energy of the CMB photons and shift the spectrum. The effect is redshift-independent, and so provides a unique probe of the structure of the universe on the largest scales.

Are we headed for a Big Crunch or a lingering fadeout? There are exciting times ahead.

Endnotes

[i] Wein's Law relates the peak temperature to the corresponding wavelength. $\lambda_{max} \propto \frac{1}{T}$

[ii] Fred Hoyle coined the term *Big Bang* during a BBC 1949 radio broadcast.

[iii] Misner, Charles W. Thorne, Kip. S.; Wheeler, John A. (1973), *Gravitation*, W. H. Freeman, ISBN 0-7167-0344-0 – trust me, this is not a book to read lightly.

[iv] This is Hubble's Law – that relates redshift to distance: redshift velocity ∝ distance where H_0 is the Hubble constant, the constant of proportionality.

[v] Actually, determinations vary from 10^{51} to 10^{60} kg depending on the assumptions – assuming a flat universe near the critical density one gets 10^{53} kg.

[vi] Based on the assumption that the universe is approximately flat.

[vii] Remember that c is the fastest any signal can go.

[viii] Planck's law produces a blackbody spectrum – a blackbody is a perfect absorber. The radiation is homogeneous and isotropic. $I = \frac{2hv^3}{c^2}\frac{1}{e^{\frac{hv}{kT}}-1}$

[ix] http://lambda.gsfc.nasa.gov/ is the resource for COBE and other NASA CMB missions.

[x] *The London Times*, 25 April 1992.

[xi] The Milky Way is the Galaxy that contains our solar system.

[xii] GTR predicts that light (photons) is affected by gravity.

[xiii] Outward pressure due to electromagnetic radiation – the pressure against a surface exposed in a space traversed by radiation uniformly in all directions is equal to one third of the total radiant energy per unit volume within that space.

[xiv] http://www.astro.caltech.edu/~lgg/boomerang/boomerang_front.htm is the resource for BOOMERanG.

[xv] Parameters like the amount of matter, the rate of expansion, and the critical density.

[xvi] Rashid Sunyaev and Yakov Zel'dovich predicted the effect in 1970s.

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Gender and International Collaborations of Academic Scientists and Engineers*: Findings from the Survey of Doctorate Recipients, 2006

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Energetics Technology Center & Northeastern University
National Action Council for Minorities in Engineering, Inc.

Introduction

SCIENCE AND ENGINEERING, as with many other enterprises in today's world, have become increasingly global. Companies conduct business in multiple nations and, in the past couple of decades, have expanded research facilities outside the United States to take advantage of a globally diverse workforce. Labor markets for scientists and engineers are increasingly less geographically bounded; talented scientists and engineers are recruited by employers without regard for their citizenship. Anecdotal evidence reported by engineers at various U.S. firms, for example, highlights the "shrinking" globe, as project teams in some companies have been collaborating on projects across international borders for 20 years or more. Consistent with the globalization of science and engineering, collaboration across international borders has become more common too.[1,2]

In academic settings, international experience has been growing in importance. Just as corporations have become multinational enterprises, so too are many universities becoming global, establishing campuses and recruitment offices outside of the United States to educate international students both here and abroad. Further, U.S. graduate programs in the sciences and engineering continue to attract substantial numbers of international students. U.S. students, too, are encouraged to study abroad in the traditional areas of languages and the

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humanities, and increasingly do so in the sciences and engineering. Finally, for faculty, an international reputation is becoming an increasingly important criterion in post-tenure academic advancement decisions.

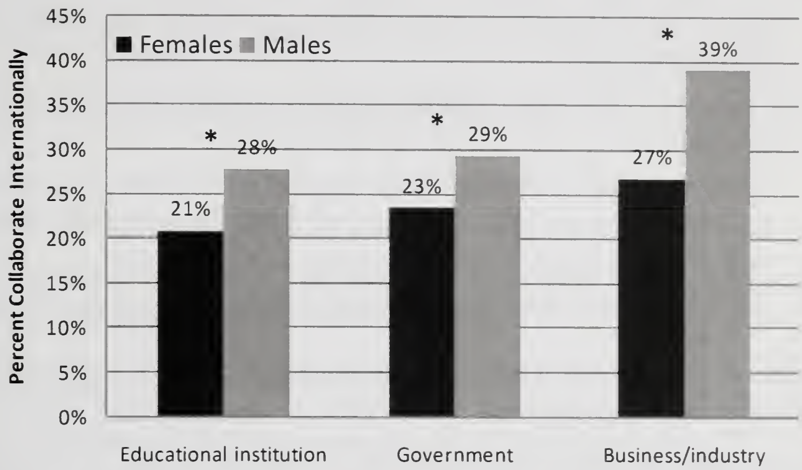
However, there are many ways in which men and women face different worlds with respect to working outside of the United States. In the corporate sector, in some cases, companies claim to protect women by not sending them to locations that might be considered too dangerous, or presume that women would not wish to go to these locations due to safety concerns. Additionally, if not to protect women from potential harm, some companies have prevented women from traveling abroad due to presumed discrimination that the women would experience in the foreign country.[3,4] As more women have become heads of state or traveled as diplomatic envoys, even nations that, from the outside, appear to have very strict rules regulating women's behavior, have shown that these rules can be flexible when necessary.[5, 6,7]

National Science Foundation data are presented in Figure 1 to show the extent to which those who hold U.S. doctoral degrees in science and engineering collaborate internationally. Two important findings from these data are: (1) women, regardless of employment sector, lag men within that sector in international collaboration and (2) those in educational institutions lag scientists and engineers employed in government and business/industry in international collaboration. Indeed, women in business and industry settings report a level of international collaboration that reveals a wider sex gap than in any other sector. Yet, the 27 percent of women scientists and engineers in business and industry who did collaborate internationally was similar to the representation of men who collaborated internationally in educational institutions.

Figure 2 shows that doctoral degree field[8] and sex interact to produce different outcomes with respect to international collaboration. Within each of the five science and engineering fields, within the educational employment sector, women's reported rate of international collaboration lags that of men – but the sex gap across the fields varies greatly. The widest gaps are in those fields in which women have made greater inroads in relative participation in recent years: life and related sciences and social and related sciences, as well as in the physical and related sciences. The gap is only 5 percent or less for women and men in computer and mathematical sciences and engineering. These disciplinary differences may be at the heart of work by Melkers and Kiopa, who found that even though there was no difference in the likelihood of women and men collaborating internationally, the nature of the support men and women received differed. Women report that they received benefits such as paper review and

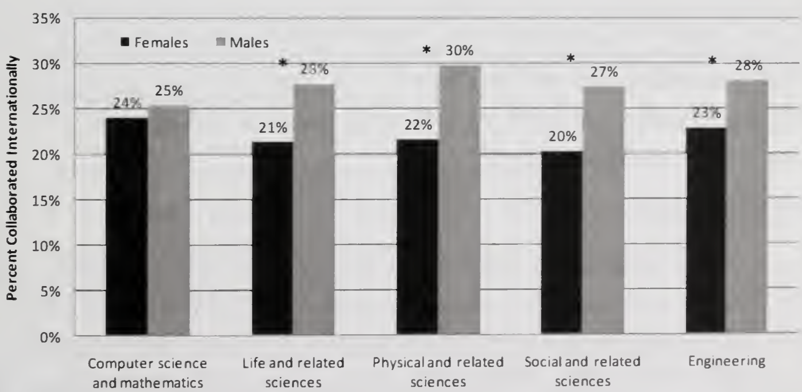
assistance with grant proposals, while men were more likely to obtain access-based rewards like nominations for awards.[9]

Figure 1. International Collaboration by Employment Sector and Sex, U.S. Doctoral-Degreed Scientists and Engineers, 2006



Source: Author's weighted analysis of National Science Foundation Survey of Doctorate Recipients, Restricted-use file. The use of NSF data does not imply NSF approval of the research, research methods or conclusions.
Note: * indicates statistical significance at alpha = 0.01.

Figure 2. International Collaboration, U.S. Doctoral-Degreed Scientists and Engineering at Academic Institutions, by Sex and Broad Field 2006



Source: Author's weighted analysis of National Science Foundation Survey of Doctorate Recipients, Restricted-use file. The use of NSF data does not imply NSF approval of the research, research methods or conclusions.
Note: * indicates statistical significance at alpha = 0.01.

This paper makes use of nationally-representative data from the Survey of Doctorate Recipients (SDR) to answer a series of questions about international collaboration by U.S. academics with doctoral degrees to better understand the differences shown in the two figures above:

- Among those who collaborate internationally, to what extent are men and women similar or different in terms of the travel they do for these collaborations?
- To what extent does international collaboration vary by race/ethnicity and sex?
- How do tenure status and rank impact international collaborations?
- In what ways are international collaborations impacted by family status issues (such as marital status and children)?
- To what extent does international collaboration differ by citizenship?

Data and Methods

Data

The SDR is a nationally-representative survey with data collected by the National Opinion Research Center under contract to the National Science Foundation every two to three years with both longitudinal and cross-sectional features. Data are longitudinal in that, once impaneled, respondents are tracked and complete the survey in each administration after earning their doctoral degree. New respondents are added to the program via a sample from the Doctorate Records File, which includes information on graduates of research doctorate programs at U.S. colleges and universities. For this paper we used only one year of data in the SDR, specifically the 2006 SDR, in which a set of questions was asked about international collaboration in a new module, as discussed below. The 2006 SDR administration had 30,800 respondents representing 711,800 doctoral-degreed scientists and engineers.

Analytical Approach

As will be discussed below, all dependent and independent variables are categorical, often with simple yes/no response categories. The principal analytical strategy was cross-tabulation, often with multiple variables or with selection of a limited group for analysis. SPSS-Windows was used to analyze the 2006 SDR restricted-use dataset. Further, due to the complex stratified sampling plan,[10] the National Science Foundation, Science Resource Statistics division recommends the use of sampling weights in analysis of the SDR data. Weighted analysis permits the generalization of results to the population from which the sample was

drawn. The large populations, then, produce many statistically significant results, even when group differences are quite small. We, therefore, call attention to those differences that are meaningful, setting as our standard for this as sex gaps where the difference of proportions is greater than 5 percentage points.[11] Because the weighted analysis yields population estimates that are quite large, routine statistical procedures indicate significance even for very small subgroup differences. For hypothesis testing—*i.e.*, testing whether the responses of women and men differed significantly—we established alpha = 0.01 for test statistics. We used chi-square tests and difference of proportions tests, as mathematically appropriate.

Dependent Variables

The specific questions of interest here (the dependent variables of interest), both with simple yes/no answers, were:

(1) International Collaboration: In performing the principal job you held during the week of April 1, 2006, did you work with individuals located in other countries? (defined as *international collaboration*).
(2) International Travel: In your work with individuals located in other countries, did you travel to a foreign country for collaborative activities? (defined as *travel abroad*).

Other items included in the module[12] were not used for this paper. We recognize that this is a very broad definition of international collaboration.

Independent Variables

Sex was the critical independent variable: most analyses compare women and men. Another key demographic variable of interest was race/ethnicity, which was coded as a three-category variable:

- Asian Americans (included Pacific Islanders)
- Underrepresented minority included African Americans, American Indians/Alaska Natives, and Hispanics (and noted as URM)
- White (non-Hispanic whites).

Anyone for whom race/ethnicity was either unknown or marked as "other" was omitted from most analyses, except as noted. To date, the literature has little information about the impact of race/ethnicity on the likelihood of collaborating, in general, or of collaborating internationally, in particular.[13] Data on participation in study abroad programs indicates that African Americans and American Indians

are less likely than White students to engage in study abroad activities and are often "first generation international travelers."[14]

The respondent's doctoral degree was used to code fields, which is provided at various levels of detail within the SDR dataset. Using the broadest field coding level, we analyzed international travel and collaboration for scientists and engineers who reported one of the following five categories as their doctoral degree field of study:

- Computer and mathematical sciences;
- Life and related sciences (note: health and medical fields are not included in this category);
- Physical and related sciences;
- Social and related sciences (includes psychology);
- Engineering.

There are two other broad fields at this level, which were omitted from the analysis: "Science and engineering related" and "Non-S&E" fields, which together had just 1,465 cases.

This paper examines issues for U.S. academics in particular, so analyses were also restricted to only those who reported being employed in an educational institution. While this includes K-12 (n=412) and two-year colleges (n=510), the overwhelming majority of cases (n=12,128) were people employed in four-year colleges and universities, medical schools and university-affiliated research centers. With both the field of study and the employment sector restrictions, the overall number of cases in the analyses was 12,351, which represents 276,541 U.S. doctoral-degreed scientists and engineers employed in academic institutions.

Several family status variables were used to capture gendered impacts described in previous work by George, Malcom and Frehill (2009).[15] First, the SDR asked about marital status, which was consolidated into three categories, consistent with those used in most social science reporting:

- Married or in a marriage-like relationship (which we refer to as married/partnered);
- Widowed, separated, or divorced;
- Never married.

Also examined was whether spouse's work status played a role in individuals' likelihood of engaging in international collaboration and then traveling associated with that collaboration. Respondents who reported that they were married or in a marriage-like relationship were asked if their spouse worked and if so, was this

work full or part time. Women in professional fields, academia included, who are married were more likely than men to indicate that their partner works at a full-time position, while men were more likely to report a spouse who has not job in the paid labor force. This suggests that academic men are more likely than their female peers to have a spouse who is in a more support-function role, thereby enabling them to travel and engage in international collaborative relationships.[16, 17, 18, 19]

There were quite a few items that asked about the presence of children in the respondent's home, to identify those respondents who did have children of various ages. Therefore the following categories were used, which are non-mutually exclusive, to capture the potential impacts of children upon *international collaboration* and *travel abroad*:

- No children living at home;
- Children under 2 living at home;
- Children aged 2-5 living at home;
- Children aged 6-11 living at home;
- Children aged 12-18 living at home;
- Children 19 and older living at home;
- Any children of any age living at home.

The literature to date suggests that the presence of children, especially young children, prevents women from accepting positions for which travel is necessary.[20, 21, 22] Therefore, the total number of children was not computed, nor was a new variable formed by crossing marital status with the children variables, which is sometimes done in the literature on the impact of family status on occupational outcomes. Hence, the analyses presented here are somewhat simplified in terms of the potential impacts that having children of various ages may have on international collaboration and travel abroad.

Individuals' geographic origin can also play an important role in the likelihood of engaging in international collaboration and/or traveling abroad associated with collaborations. Two measures were used to capture possible impacts associated with prior international experience: citizenship and holding a bachelor's degree from a non-U.S. institution. Citizenship was coded using the four-category variable available in the SDR:

- U.S. citizen (native born);
- U.S. citizen (naturalized);
- Non-U.S. citizen, permanent resident;
- Non-U.S. citizen, temporary resident.

The U.S. citizen, naturalized category is the group that poses the most theoretical challenges when studying how citizenship impacts educational and occupational outcomes because of the heterogeneity of this group. That is, it includes individuals who arrived in the United States as children and, fundamentally, were raised within the U.S. system, as well as individuals who arrived quite a bit later after having gone through other educational systems. The social forces associated with each of these groups, obviously, are quite different but age of arrival in the United States is not a variable available in the SDR. Therefore, we also used another commonly used variable as a proxy for age of arrival: the world region in which the individual received her or his bachelor's degree.[23] The regions were:

- United States;
- Americas (rest of North America, Central and South America and the Caribbean);
- Europe;
- Asia;
- Africa; and
- Oceania (Australia, New Zealand and other Pacific Islands).

Origin measures are intended to account for the possible impacts of having prior international networks, mentors, *etc.* that could be associated with completing a bachelor's degree in a country other than the United States, which has been shown to positively affect the likelihood of international collaboration, especially among women.[24] Citizenship may also have a specific effect beyond that associated with the area of an individual's bachelor's degree: individuals who have already experienced living in an international setting—that is, those who are non-native-born U.S. citizens—may be more comfortable and predisposed to engage in research opportunities that necessitate travel outside the United States than those who do not have this experience (*i.e.*, U.S. citizens by birth).

Rank and tenure status are also likely to impact international collaboration and travel abroad. The relevant SDR variables—*i.e.*, rank with its eight categories and tenure status with its five, produces a 40-cell matrix—but these were simplified/reduced to the following categories:

- Tenured full professor;
- Tenured associate professor;
- Tenure track senior faculty (associate or full);
- Assistant professor (includes tenured and untenured tenure-track junior faculty in assistant professor, lecturer, and instructor positions);
- Non-tenure track (all ranks of faculty not tenured and not on a tenure track).

The literature indicates that an international reputation is becoming more important for faculty in terms of advancement to the full professor rank but may not be as critical for those who are working towards tenure and promotion to the associate professor rank.[25, 26]

Results

Table 1 shows the overall sex distribution within each of dependent and independent variables used in our analyses. On most of the key demographics, there were few differences between women and men. The largest differences are in the way women and men are distributed across the categories of Rank/Tenure status and fields. Nearly half of the men but just over one-in-five women are in tenured full professor positions with women much more likely than men to be in non-tenure track positions. A far higher proportion of women are in the social and behavioral sciences than men, while men are much more likely than women to be in the computer and mathematical sciences, engineering, and physical sciences. Indeed, more than 80 percent of women are in the life and social and behavioral sciences, while men are less concentrated.

On the family status measures, women and men were somewhat different. Women were less likely than men to be married and those who were married or in a marriage-like relationship were far more likely than men to report that their spouse works full time, consistent with the research literature in this area. Whereas 81 percent of married/partnered women reported that their spouse works a full-time job, just under half of married/partnered men reported this. Nearly one-in-three married/partnered men reported that their spouse was not employed.

Race/ethnicity, Sex and Discipline

To what extent does the likelihood of collaborating internationally vary by race/ethnicity and sex? How does field affect international collaborations? Table 2 shows that when we control for both field and race/ethnicity, there were fewer substantial sex differences in collaboration among U.S. academics than when we did not control for these three variables. That is, here we limit ourselves to the group in the first two bars shown in Figure 1 and then we drill down into disciplines while simultaneously controlling for race/ethnicity, suggesting that the explanations for the gender gap noted in Figure 1 are complex.

Table 1. Dependent and Independent Variables by Sex: U.S. Doctoral-Degreed Recipients in Engineering and Science Employed at U.S. Educational Institutions in STEM Fields, 2006

	Female	Male	Total
Dependent Variables:			
International Collaboration	20.9%	27.7%	25.6%
Travel Abroad	46.3%	49.9%	49.0%
Independent Variables:			
Minority Status			
Asian	13.4%	14.1%	13.9%
Underrepresented minority	10.5%	7.1%	8.2%
White	76.1%	78.8%	77.9%
Rank/Tenure Status			
Full, tenured	22.0%	43.7%	37.4%
Associate, tenured	21.1%	19.0%	19.6%
Senior, tenure-track	22.8%	15.7%	17.8%
Junior, tenure-track	4.6%	4.6%	4.6%
Non tenure-track	29.5%	17.1%	20.7%
Field			
Computer and mathematical sciences	5.1%	9.8%	8.3%
Life sciences	33.6%	29.2%	30.6%
Physical sciences	9.1%	18.3%	15.4%
Social and behavioral sciences	47.8%	27.9%	34.2%
Engineering	4.4%	14.8%	11.5%
Citizenship			
U.S., native	79.1%	76.4%	77.2%
U.S., naturalized	9.7%	12.6%	11.7%
Non-U.S., permanent resident	6.6%	6.5%	6.6%
Non-U.S., temporary resident	4.6%	4.5%	4.5%
Region of bachelor's degree institution			
United States	85.8%	83.4%	84.0%
Americas	1.8%	1.8%	1.8%
Europe	2.3%	2.5%	2.5%
Asia	9.6%	11.1%	10.7%
Africa	0.4%	1.0%	0.8%
Oceania	0.1%	0.2%	0.2%
Marital Status			
Married or a marriage-like relationship	74.3%	85.4%	79.9%
Widowed, separated, or divorced	11.0%	6.1%	7.7%
Never married	14.6%	8.4%	10.4%
Children Living in Household			
No children	55.7%	52.8%	53.8%
Child under 2	21.2%	16.8%	18.2%
Child 2-5 years of age	30.9%	26.4%	27.7%
Child 6-11 years of age	37.6%	37.4%	37.5%
Child 12-18 years of age	36.8%	43.3%	41.3%
Child 19 or older	11.5%	17.9%	16.0%
Any child of any age	44.3%	47.2%	46.2%
Spouse's work status			
Employed full-time	81.0%	48.8%	58.1%
Employed part-time	7.7%	20.5%	16.8%
Not employed	11.2%	30.7%	25.1%
N (weighted)	87,243	189,298	276,541

Source: Author's analysis of National Science Foundation, Survey of Doctorate Recipients restricted-use data file (2006). The use of NSF data does not imply NSF approval of the research, reseach methods or conclusions.

Table 2 shifts attention to the way that race/ethnicity and sex *together* impact international collaboration. Within various ethnic groups, there are some important sex differences. Among underrepresented minorities (URMs), men were more likely than women to collaborate in the engineering and computer and mathematical sciences, while women were more likely than men to indicate that they were involved in international collaborations in the physical and related sciences. For Asian Americans, men were more likely than women to report collaborating in the life and related sciences and engineering. For whites, though, there is a substantial sex difference in international collaboration among those in the physical and related sciences with 31 percent of white males but just 21 percent of white females reportedly involved in international collaboration. The engineering sex difference that is on the order of a 10 percent gap in international collaboration between men and women in engineering is not evident for whites.[27]

Table 2. Percent Reporting International Collaboration and Travel Associated with Collaboration by Broad Field, Sex and Ethnic Category, U.S. Doctoral-Degreed Academics, 2006

		Asian		URM		White		Total	
		Collaborate	Travel	Collaborate	Travel	Collaborate	Travel	Collaborate	Travel
Computer and mathematical sciences	Female	29.2%	48.1%	19.9%	56.9%	22.6%	46.7%	23.9%	47.7%
	Male	25.5%	69.2%	29.0%	76.8%	24.9%	42.7%	25.3%	50.7%
Life and related sciences	Female	14.5%	47.5%	23.0%	55.1%	22.7%	33.6%	21.2%	37.2%
	Male	22.4%	41.7%	25.2%	56.2%	28.8%	41.2%	27.6%	42.1%
Physical and related sciences	Female	20.0%	32.0%	28.7%	44.0%	21.2%	61.4%	21.5%	55.1%
	Male	25.6%	52.8%	20.3%	48.1%	31.1%	52.9%	29.7%	52.7%
Social and related sciences	Female	23.7%	57.2%	19.1%	56.0%	20.1%	46.6%	20.2%	48.6%
	Male	28.7%	60.7%	26.2%	54.1%	27.3%	50.2%	27.3%	51.3%
Engineering	Female	13.0%	49.6%	18.1%	75.0%	27.8%	74.8%	22.7%	70.8%
	Male	23.6%	69.2%	27.5%	60.0%	29.6%	55.0%	28.0%	58.4%

Notes: (1) URM = underrepresented minority, includes American Indians/Alaska Natives, African Americans, Hispanics, Native Hawaiians and Other Pacific Islanders, and Multiple Race. (2) The Travel question was contingent on the Collaboration question, that is, of those who indicated that they worked with people in other countries, shown here is the percentage who said that they traveled to another country. (3) Grey cells indicate those on which the difference of proportions was .05 (i.e. a 5 percent gap between men and women), which is interpreted as a meaningful association. Chi-square tests were significant for all except a handful of sex differences at the alpha = 0.01 level. The non-significant results were as follows: Collaboration: URMs in Life and related sciences and Whites in Engineering. Travel: Asians in Social and related sciences and URMs in Life and related sciences, Physical and related sciences, and Social and related sciences.

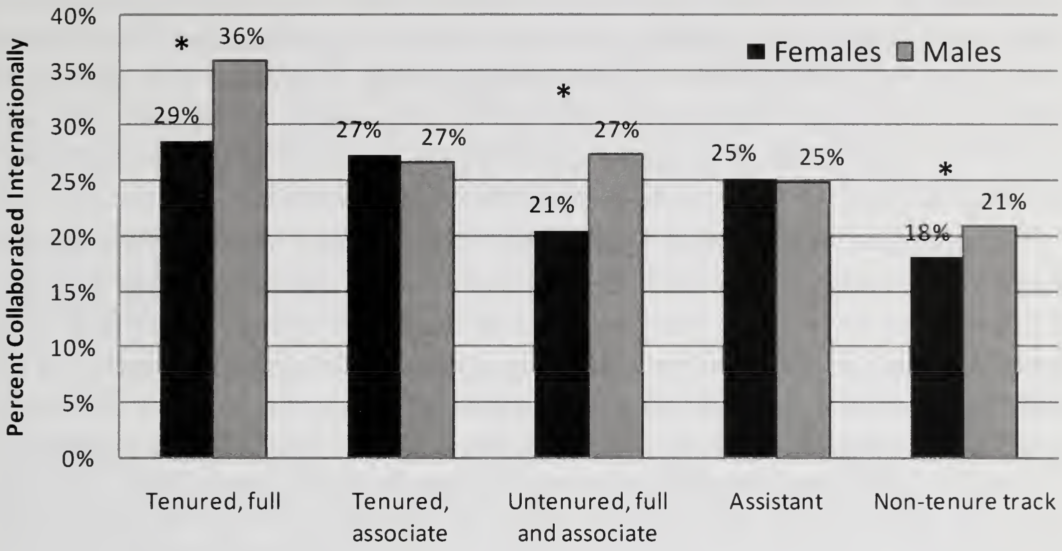
Source: Author's analysis of National Science Foundation, Survey of Doctorate Recipients restricted-use data file (2006). The use of NSF data does not imply NSF approval of the research, reseach methods or conclusions.

Among those who reported that they engaged in an international collaboration, one of the key follow-up questions related to whether or not the respondent traveled abroad. Whereas many of the sex differences on the general variable measuring international collaboration were rather small, the sex differences in the percentage of respondents who reported that they traveled abroad are generally larger, as shown in Table 2. For example, Asian males in three of the five disciplines—computer and mathematical sciences, physical and related sciences, and engineering—were much more likely than Asian females to report that they traveled abroad for their international collaborative work. URM males in computer and mathematical sciences were also substantially more likely than females in this same ethnic category to indicate that they traveled abroad. Engineering is interesting because even though URM females were less likely to indicate that they were involved in international collaboration than URM males, those who were involved in these collaborations were quite a bit more likely than men to indicate that they traveled abroad for the collaboration. Likewise, white females in engineering, who reported a similar chance of being involved in an international collaboration as white male engineers, were also substantially more likely than men to report that they traveled abroad. Indeed, three-fourths of women engineers who were either URM or white and were involved in international collaboration traveled abroad – some of the highest rates shown in Table 2.

Rank and Tenure Status

Tenure status and rank had a substantial impact upon rates and the sex gap in international collaboration (Figure 3). Those who were at the top ranks of academia reported the highest rates of international collaboration within their respective sex group: 36 percent of male and 29 percent of female full professors were involved in international collaborations. This sex gap was replicated for those who were untenured but in senior-level ranks. It is noteworthy, though, that among associate (tenured) and assistant professors (tenured and untenured) there was no sex gap in international collaboration. About one-in-four assistant professors and just a little more than one-in-four associate professors of both sexes indicated that they were involved in international collaboration. These findings suggest that there may be important cohort effects that impact the overall sex gap in international collaboration.

Figure 3. International Collaboration of U.S. Doctoral-Degreed Academics by Rank and Tenure Status and Sex, 2006



Note: Actual percent for women, tenured, associate professors was 27.3%, men, 26.6%. Not statistically different. * indicates statistical significance at alpha = 0.01 level.
Source: Author's weighted analysis of National Science Foundation Survey of Doctorate Recipients, Restricted-use file. The use of NSF data does not imply NSF approval of the research, research methods or conclusions.

Family Status

Marital status had a stronger impact on international collaboration for men than for women, although the data reported in Table 3 most likely conflates age effects with marital status effects and the impact of children. That is, those who had never been married are likely, also, to have a younger average age than those who report any of the other marital statuses and, indeed, there is a rather narrow gender gap in international collaboration among those faculty members. Married men were the most likely group to report international collaboration (29 percent) and the sex gap in international collaboration was widest among those who reported that they were married or in a marriage-like relationship. In the literature on the sex gap in pay in corporate settings, this has come to be referred to as the "marriage bonus" for men.[28,29] While marital relationships have undergone important changes in the past 30 years, it is still the case that men are more likely to reap a range of health and personal service benefits from marriage in contrast to single men and married women.

The likelihood that respondents reported that they traveled abroad, also shown in Table 3, shows that among those who reported an international collaboration, single men and women, whether they have been married or not, were more likely than married men and women to indicate that they traveled abroad for the collaboration. The least likely group to report travel abroad was married women (at 44 percent), while the most likely group was widowed, separated or divorced women (57 percent). It seems that marital status has a greater impact on women's likelihood of traveling than on men's.

Spouse's employment status had little impact on the likelihood of international collaboration for both men and women, and of traveling abroad for collaborations for women. Men who had an employed spouse (either full or part time) were less likely than those who had a spouse who did not work in the paid labor force to travel for international collaborations.

Table 3. International Collaboration and Travel Associated with Collaboration of U.S. Doctoral-Degreed Academic Scientists and Engineers, by Family Status, 2006

	Collaborate			Travel Contingent on Collaboration		
	Female	Male		Female	Male	
Marital Status*						
Married/partnered	21.1%	28.6%	*	44.4%	49.3%	*
Widowed, separated, divorced	22.3%	25.6%	*	56.6%	54.3%	*
Never Married	18.8%	20.9%	*	47.9%	53.6%	*
N (weighted)	87,243	189,298		18,260	52,512	
Children, by Age Group						
No children	21.7%	27.0%	*	42.7%	51.8%	*
Under 2 years	19.9%	27.7%	*	42.2%	45.1%	*
2 - 5 years	19.1%	27.0%	*	36.1%	45.3%	*
6 - 11 years	19.4%	29.0%	*	45.7%	49.5%	*
12 - 18 years	23.6%	29.6%	*	41.4%	50.3%	*
19 and older	19.0%	26.4%	*	47.5%	55.6%	*
Any age	19.9%	28.6%	*	41.5%	49.4%	*
Spouse's Employment Status*						
Employed full time	20.9%	28.1%	*	45.7%	47.2%	*
Employed part time	25.3%	32.1%	*	32.9%	47.8%	*
Not employed	20.4%	26.9%	*	45.1%	54.1%	*
N (weighted)	64,851	161,717		13,715	46,198	

Notes: Overall N (weighted) similar for the children variables as marital status, but since these represent seven different variables rather than categories associated with one variable (as does marital status and spouse's employment status) answers are not mutually exclusive. * indicates significance at alpha = 0.01.

Source: Author's analysis of National Science Foundation, Survey of Doctorate Recipients restricted-use data file (2006). The use of NSF data does not imply NSF approval of the research, reseach methods or conclusions.

The presence of children had implications for international collaboration and, especially, travel associated with these collaborations. Childless women were only ever-so-slightly more likely than women with children to report that they collaborated internationally (22 percent for childless women and 20 percent for those with a child of any age), suggesting that the presence of children, per se, was not a specific deterrent to engaging in an international collaboration. Likewise, men's reported participation in international collaborations varied little for men with versus those without children. The sex gap, though, is quite clear regardless of children's ages. That is, the sex gap is smallest among those without children and is widest for those who report that they have at least one elementary-school aged child living in their home.

Women with children were less likely than men with children to travel as shown in Table 3: 42 percent of women and 49 percent of men with children currently living in their home indicated that they traveled abroad. Ironically, though, when specifically examining the likelihood of traveling abroad, the findings are rather different. At the most macro level, indeed, men were more likely than women to report that they traveled abroad regardless of whether they had children and regardless of children's ages. The sex gap in traveling abroad was lowest for men and women with 6-11 year olds at home than for any other group. Women who had children aged 2-5 years—too big to carry and of pre-school age—were least likely to travel. Childless women were about as likely as those with children under 2 years or between the ages of 12 and 18 to travel abroad. For both men and women, though, those with children 19 years or older living at home were the most likely to travel abroad – again, though, this finding may likely be associated with an age effect.

International Origins: Citizenship and Bachelor's Degree Region

As shown in Table 4, women's citizenship status had minimal impact on the percentage of women who indicated that they were involved in international collaboration, ranging from 20 percent among native-born U.S. citizens to 24 percent among naturalized U.S. citizens. For men, though, citizenship had a larger impact on international collaboration. Just one-in-five men who were temporary residents reported an international collaboration but 32 percent of men who were naturalized U.S. citizens reported they were collaborating internationally. With the exception of non-U.S. temporary residents, men were much more likely than women within the same citizenship status to report that they were involved in an international collaboration.

Table 4. International Collaboration and Travel Associated with Collaboration of U.S. Doctoral-Degreed Academic Scientists and Engineers, by Origin, 2006

	Collaborate			Travel Contingent		
	Female	Male		Female	Male	
Citizenship Status						
U.S., native	20.4%	27.3%	*	44.1%	47.0%	*
U.S., naturalized	23.5%	31.8%	*	56.2%	65.7%	*
Non-U.S., permanent resident	22.6%	30.7%	*	54.2%	50.1%	*
Non-U.S., temporary resident	22.7%	20.0%	*	48.4%	44.9%	*
N (weighted)	87,243	189,298		18,258	52,513	
Bachelor's Degree Region						
Americas	35.1%	35.9%		51.9%	68.5%	*
Oceania	33.3%	42.4%		28.6%	34.8%	
Europe	30.0%	43.3%	*	56.6%	56.3%	
Africa	24.7%	27.2%		63.0%	59.3%	
Asia	17.7%	23.4%	*	50.5%	62.5%	*
United States	21.1%	27.6%	*	44.2%	47.4%	*
N (weighted)	82,932	181,311		17,473	50,230	

Source: Author's analysis of National Science Foundation, Survey of Doctorate Recipients restricted-use data file (2006). The use of NSF data does not imply NSF approval of the research, reseach methods or conclusions. Note: * indicates significant sex difference at alpha = 0.01.

Further, while there were few differences in women's likelihood of engaging in international collaboration based on citizenship status, there were broad differences in women's reporting that they traveled internationally. The sex gaps in the likelihood of traveling abroad were generally smaller than those shown for international collaboration. The most likely group to report traveling abroad for an international collaboration were U.S. naturalized men (66 percent), which was true for women too – *i.e.* naturalized U.S. women were most likely among women to indicate that they had traveled abroad for international collaboration (56 percent). The least likely groups were non-U.S. temporary resident men (45 percent) and U.S. native-born women (44 percent).

European-origin men and those from Oceania were most likely to report that they engaged in international collaboration. Within each of the regional groups based on bachelor's degree origin, men were more likely than women to report that they collaborated internationally. Women who had earned their bachelor's degrees in the Americas (35 percent) followed by Oceania (33 percent) and Europe (30 percent) were the most likely to report that they engaged in international collaboration. Women who earned their bachelor's degree in the

United States were among the least likely to engage in international collaboration. Men and women who had earned bachelor's degrees from institutions in Africa or Asia were among the least likely to report international collaborations. To some extent this finding may be related to the earlier stage of the tertiary education systems in nations on those continents, particularly the largest (in terms of population) nations of China and India. For example, interviewees and findings from workshops with international collaboration participants[30,31] noted that an individual's connections to professors at their foreign undergraduate institution sometimes formed the basis for an international collaboration among those who held degrees from European universities. Therefore, in the future it is possible that those who hold bachelor's degrees from institutions in Africa and Asia may also reap international collaboration connections from these past associations.

The sex gap among those who reported that they traveled abroad for an international collaboration varied greatly based on the bachelor's degree region. Among those who received a bachelor's degree from a European, U.S., or African institution, there was a negligible difference in the percentage of men and women who reported that they traveled abroad for international collaboration. The gap was much wider for scholars who received their bachelor's degree from an institution in Asia (12 percent gap) or the Americas (16 percent gap). Men who had earned bachelor's degrees from institutions in the Americas were the most likely to report that they traveled abroad to participate in an international collaboration (68 percent), while 63 percent of women who had been trained in Africa were most likely to report that they traveled abroad for an international collaboration.

Conclusions

The likelihood of engaging in an international collaboration and of traveling abroad for collaboration differs along many dimensions: discipline, race/ethnicity, sex, family status, and citizenship. In general, the key differences are noted on the first of these two variables—international collaboration—with smaller gaps on the second variable, *i.e.*, travel abroad. It should be remembered that the second variable was contingent on the first, so that when controlling for whether or not a person collaborates internationally, the likelihood of traveling abroad is less dependent upon a host of independent variables.

It is important to note that holders of doctoral degrees from U.S. colleges and universities who were employed in academia were less likely than those employed in business/industry or government to engage in international collaborative research. In today's shrinking world, in which students are

increasingly becoming involved in global issues, faculty involvement in international work, in general, should be a matter of public concern.

Our findings show that the relationship between sex and international collaboration is quite complicated and, to some extent, affected by the interaction of sex with variables like field, rank and tenure status, and discipline. Women's concentration in the life, social and behavioral sciences suggests a need to further examine the subfields within these disciplines as possibly shaping women's likelihood of engaging in international collaboration. Finkelstein *et al.* (2009), for example, showed that "internationalization" for faculty members in humanities and social sciences tended to involve incorporation of global content in the classroom, while that of STEM field faculty involved research with international colleagues. The SDR data, however, were inadequate to tease out these differences, since the survey question implemented a broad and general definition of international collaboration.

That 43 percent of the men who were in the five science and engineering fields examined and employed in academic settings were full professors compared to just 22 percent of the women and that women showed a greater likelihood of being in non-tenure track positions, was quite important. Among tenured and tenure track faculty at the assistant and associate levels, there was no discernible sex gap in international collaboration but the gap at the full, tenured level was quite large. On the one hand, this suggests a cohort effect, possibly due to a mechanism such as cumulative disadvantage.[32] On the other hand, it may indicate that caution needs to be exercised in monitoring faculty members as they advance to insure that women and men have similar opportunities to engage in international collaborations.

The analyses conducted here are best described as exploratory, suggesting that subsequent multivariate analysis using logistic regression would likely be a fruitful analytical strategy to tease out the factors that are most salient. Being able to examine how marital status, presence of children of various ages, field, and rank/tenure status have differential effects for women's and men's international collaboration will be important in developing strategies for encouraging all faculty to participate.

Endnotes/References

[1] Peters, Michael A. 2006. "The rise of global science and the emerging political economy of international research collaborations." *European Journal of Education 41(2):* 225-244.

[2] National Science Board. 2010. *Science and Engineering Indicators 2010.* Arlington, VA: National Science Foundation (NSB 10-01).

[3] Benokraitis, Nijole V. and Joe R. Feagin. 1995. *Modern Sexism: Blatant, Subtle and Covert Discrimination, 2nd Edition.* (Upper Saddle River, NJ: Prentice Hall). The first edition appeared in 1986.

[4] Adler, Nancy J. 1987. "Pacific Basin Managers: A Gaijin, Not a Woman." *Human Resource Management 26(2):* 169-191.

[5] Ibid.

[6] Altman, Yochanan and Susan Shortland. 2008. "Women and International Assignments: Taking Stock—A 25-Year Review." *Human Resource Management 47(2):* 199-215.

[7] Napier, Nancy K. and Sully Taylor. 2002. "Experiences of Women Professionals Abroad: Comparisons across Japan, China and Turkey." *International Journal of Human Resource Management 13(5):* 837-851.

[8] While there are important disciplinary differences in these findings, more details about these can be viewed elsewhere. Frehill, Lisa M. and Kathrin Zippel. "Appendix A. International Collaboration by Employment Sector and Sex, 2006 for Selected Science and Engineering Disciplines" available online at http://nuweb.neu.edu/zippel/nsf-workshop/docs/SDR_Oct22_2010.pdf.

[9] Melkers, Julia and Agrita Kiopa. 2010. "The Social Capital of Global Ties in Science: The Added value of International Collaboration." *Review of Policy Research*: 389-414.

[10] See http://www.nsf.gov/statistics/srvydoctoratework/ for details.

[11] There are no standards for specifying what constitutes a "meaningful" gap. The difference of proportions is common to use with 2 x 2 contingency tables of the type constructed for many of the analyses in this article. As this measure approaches 1 (or 100 percent when represented in that way) there is evidence for the assertion that the association is strong and when the difference of proportions is closer to 0, the association between the two variables is said to be weak. Nielsen, Joyce McCarl. 1990. *Sex and Gender in Society: Perspectives on Stratification, 2nd Edition.* (Long Grove, IL: Waveland Press). Agresti, Alan and Barbara Finlay. 1997. *Statistical Methods for the Social Sciences, 3rd Edition.* (Upper Saddle River, NJ: Prentice Hall).

[12] There were an additional six items beyond those described here. According to the National Science Foundation, the data from these items were not released due to data quality problems.

[13] Smykla, Emily and Kathrin Zippel. 2010. "Literature Review: Gender and International Research Collaboration." Available online at http://nuweb.neu.edu/zippel/nsf-workshop/.

[14] Frehill, Lisa M. 2008. "Executive Summary" in *Professional Women and Minorities: A Total Human Resources Data Compendium*. (Washington, DC: Commission on Professionals in Science and Technology).

[15] George, Yolanda, Shirley Malcom, and Lisa M. Frehill. 2009. "Evaluation of the AAAS Women's International Scientific Cooperation (WISC) Program" (Washington, DC: American Association for the Advancement of Science).

[16] Hertz, Rosanna. 1986. *More Equal than Others: Women and Men in Dual-Career Marriages*. (Berkeley, CA: University of California).

[17] Ledin, Anna, Lutz Bornmann, Frank Gannon and Gerlind Wallon. 2007. "A Persistent Problem: Traditional Gender Roles Hold Back Female Scientists." *EMBO Reports 8(11):* 982-987.

[18] Shauman, Kimberlee A. and Yu Xie. 1996. "Geographic Mobility of Scientists: Sex Differences and Family Constraints." *Demography 33(4):* 455-468.

[19] Suitor, J. Jill, Dorothy Mecom, and Ilana S. Feld. 2001. "Gender, Household Labor, and Scholarly Productivity among University Professors." *Gender Issues 19(4):* 50-67.

[20] Gustafsson, Per. 2006. "Work-Related Travel, Gender, and Family Obligations." *Work, Employment and Society 20(3):* 513-530.

[21] Op. cit., Shauman and Xie, 1996.

[22] Tharenou, Phyllis.: 2008. "Disruptive Decisions to Leave Home: Gender and Family Differences in Expatriation Choices." *Organizational Behavior and Human Decision Processes 105*: 183–200.

[23] In some studies, location of high school completion is taken as a good proxy for whether the individual would be considered more a product of the U.S. versus some other educational and cultural system. Here, though, we lacked that measure. Since it is still relatively uncommon for non-U.S. students to travel to the United States to earn a bachelor's degree, this may be a valid demarcation point for defining those who are more culturally U.S. versus non-U.S.

[24] Op. cit., George *et al.* 2009.

[25] Finkelstein, Martin J., Elaine Walker, and Rong Chen. 2009. "The Internationalization of the American Faculty: Where are we? What Drives or Deters Us?" Conference Presentation: The changing academic profession over 1992-2007: International, comparative, and quantitative perspectives, organized by the Research Institute for Higher Education, Hiroshima University and Research Institute for Higher Education, Hijiyama University. http://en.rihe.hiroshimau.ac.jp/pl_default_2.php?bid=100132.

[26] Op. cit., George *et. al*. 2009.

[27] There were four of the 30 cells in the ethnicity by sex by discipline matrix for the percentage of individuals who had reported an international collaboration in which there were less than 1,000 cases. Three of these were for URM women: computer and mathematical sciences (326), physical sciences (585) and engineering (331). The fourth cell was Asian American women in computer and mathematical sciences, just 995 individuals in this cell had collaborated internationally.

[28] Budig, Michelle J. and Paula England. 2001. "The Wage Penalty for Motherhood." *American Sociological Review* 66: 204-225.

[29] Chiodo, Abigail J. and Michael T. Owyang. 2002. "For Love or Money?: Why Married Men Make More" *The Regional Economist.* St. Louis, MO: Federal Reserve Bank. April 2002.

[30] Op. cit., George *et al.* 2009.

[31] Hogan, A., K. Zippel, L. Frehill. 2010. "Report: International Workshop on International Research Collaboration." (Boston, MA: Northeastern University) accessed online at http://nuweb.neu.edu/zippel/nsf-workshop/.

[32] Valian, Virginia. 1998. *Why So Slow? The Advancement of Women.* (Cambridge, MA: MIT Press).

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SCIENCE IS MURDER
Washington Academy of Sciences
December 21, 2010
Minutes

Ron Hietala
Philosophical Society

It was a cold night in a city that knows it can't keep a secret. A crowd of scientists schmoozed around a marbled lobby in a downtown office building, talking quietly and eating hors d'oeuvres.

At about 7 pm, they wandered into a conference room for the occasion of the second "Science is Murder" program of the Washington Academy of Sciences, December 21, 2010.

Academy President Mark Holland welcomed everyone. He made a pitch for membership in the Academy and extolled the virtues of the *Journal of the Washington Academy of Sciences*. He expressed appreciation for donations of refreshments from Barrel Oak Winery and the Martarella Winery. (Do we see a pattern here?)

President Holland turned the microphone over to Kathy Harig, owner of the Oxford, Maryland bookstore "Mystery Loves Company," to moderate the immoderately mysterious panel. Ms. Harig introduced the panelists, four accomplished authors of mysteries involving science: Lawrence Goldstone, Ellen Crosby, Louis Bayard, and Dana Cameron. While most mysteries involve science, these authors' works do so in more meaningful ways.

Lawrence Goldstone's books are usually historical (no surprise, since he holds a PhD in American constitutional history). They include *Out of the Flames*, *The Friar and the Cipher*, and *Anatomy of Deception*. His latest book, *The Astronomer*, is set in Paris among the heretic-burning of the 1500s. In it, a young man is pressed into the service of the Inquisition, where he acquires doubts about the wisdom and justice of what is going on as he pursues his investigations and learns of scientific discoveries.

Ellen Crosby is a freelance journalist. Her mysteries are all set in the Virginia wine country, where she lives. Some of the attendees had been drinking the products of those very vineyards earlier. She has five books in

her wine country series. Their alliterative titles include *The Viognier Vendetta*, *The Riesling Retribution*, and *The Bordeaux Betrayal.*

Louis Bayard has written three historical thrillers: *The Black Tower*, *The Pale Blue Eye*, and *Mr. Timothy*. He has earned high praise from *The New York Times* and *The Washington Post*. The *Post* placed him "in the upper reaches of the historical thriller league" and the *Times* placed him on its Notable Authors list for 2009. The central character of his fiction, Eugene Francois Vidocq, was an actual detective in the 1800s, at the beginning of scientific forensic analysis.

Dana Cameron was the only scientist on the panel. (It's unusual for an archeologist to be referred to as the scientist in the room, Ms. Cameron volunteered.) She writes the Emma Fielding archeological mysteries. She won the 2007 Anthony award for best paperback original and the 2008 Agatha award for best short story. The Emma Fielding character of her books asks questions similar to the ones Ms. Cameron does in her archeology.

Ms. Harig asked the panelists: "None of your novels are weighty, scientific tomes. How do you balance the science and the mystery aspects when your readers might be new to the science you discuss?"

Cameron: There are common threads. Many of the procedures and concerns are the same. Detectives, like scientists, try to maximize the usefulness of the data. To speak to the uninitiated, I often have a new graduate student, a kid who wanders up to the project, or a reporter on the site. By explaining matters to such characters, I can get the readers educated without lecturing to them.

Bayard: For me, it is good that I write historical mysteries, because it is a subtractive process. You have to go back and figure out all the things that people didn't know. And they are many. *Black Tower* is set in 1818 Paris. They knew nothing of DNA or even bacteriology. But Vidocq, the hero, was in fact the father of modern criminology. He was the first to use ballistics and plaster of Paris imprints. He was the first to recognize the implications of fingerprints. It is exciting to me that, with all the differences and advantages current detectives have, the spirit of Vidocq lives on.

Crosby: I'm a journalist. When I started to write mysteries set in the wine country, the only thing I knew was that I liked to drink wine. I did what any journalist does; I asked a lot of questions. I like explaining something nobody understands and making it interesting and fun. My neighbor,

Donna Andrews (one of last year's panelists) has a concept she calls the "info dump." You can have enormous gobs of information about something like, say, how to spray for powdery mildew. Too many details like that can quickly suffocate the plot. You've got to weave the winemaking in. I talk to people. I talk to the winemaker. I write what I learn from them and use their words as my characters' words. In the right amounts and the right context, it can make the story more interesting.

Goldstone: I'm pleased to be here, because I get to say something every writer dreams of saying (pause) – "I'd like to thank the Academy."

There is a balance. For our kind of audience, readers will stay with you as long as you don't "dull them out." It might be more of a challenge for a different kind of audience, but all of us write for people whose interests go beyond their own disciplines. As long as the technical aspects can be woven into the plot and spoken from interesting characters, the interest of the audience will hold. Even with historical characters, you can put words in their mouths. In *Astronomer*, Rabelais showed up. He was, historically, such an outrageous character that it's hard to imagine something he would not have said. I don't find it such a difficult balance, and I get as many comments favoring the informative parts as the entertaining plots.

Harig: Dana, you give us insight into the working life of an archeologist in your Emma Fielding books. Are you aiming for accuracy, suspense, or both? How would you describe her character and her involvement with crime?

Cameron: Both. One of my goals was to depict archeology in realistic fashion. I wanted to let people know archeology happens everywhere, not just in Greece and Egypt. I'd read a lot of books where archeologists were funky, unrealistic, sometimes unsavory, adventurers – Indiana Jones types. I wanted to let them know we are just mild mannered, professorial types.

Archeology is suspenseful. Often the surprise is on last day of the dig. It is a proven fact. It will be when it's raining, when half the crew has already gone home, when you have no more money and no more time.

Emma and her relationship with crime, that's a good question. She gets involved with a person who's there. She realizes she has the ability to take clues from the past and reconstruct what went on. She feels she should, because she can, and it involves someone close to her. She gets engaged and embroiled, to the point where, by book six, she is thinking about whether she should continue teaching archeology or take up forensics for real.

Harig: What are your favorite digs that you've been on, and how do they find their ways into your books?

Cameron: All of them! I've worked on fabulous sites. The one that started me writing was an English fort site on the coast of Maine, roughly contemporary with Jamestown. It lasted only a year, 1607 – 1608. It was a perfect time capsule. My boss and I were surveying the site, and a guy came out with a gun, to steal artifacts. There were no valuable artifacts; it was a collection of broken household trash. Most of my books are set in New England, because of that experience. They reflect the historic houses I've worked on there.

I've also worked at the British Museum and I was a Fellow at the Winterthur Library and at the Peabody Essex Library. Behind the scenes there is a treasure of good artifacts. I was writing my fourth book when I should have been writing a monograph. My books do reflect the research sites, but I put better artifacts in the books. It's more fun that way.

Harig: Ellen, your character comes to Virginia from France. Her father died and she comes to take over the winery. What suggested that to you?

Crosby: Well, first, we should be glad I wrote about a vineyard. If it had been a dairy, we would be drinking milk tonight.

How did I get into writing about Vineyards? I was posted to London in the 1990s. There I wrote a book about Moscow. On a holiday back here, we had a friend who, when he came to dinner, always brought a Virginia wine over. My husband, who is French, would always look at the bottle and wonder, should we use this for the vinaigrette or what? Then one day, the friend rented a van and took us, the whole family, on a tour of Virginia wineries.

Back in London, my publisher asked, "What did you do on holiday?" I told her about the terrific weekend we'd had, and she said, "That would be a great setting for a book." She pushed pretty hard, and I thought, "I will write one."

I got out a map of Virginia and found the nearest vineyard to my house, and that set my next book at the Swedenburg Vineyard in Middleburg. And that's the very scientific explanation of how my books got located in Virginia wine country.

Harig: But you met a very interesting person there.

Crosby: I did. Juanita Swedenburg welcomed me and taught me everything she knew about growing grapes and winemaking. She had been

horrified to discover it was against the law to ship wine to New York. She had a friend, a local lawyer who sued New York. New York sued back. It became a constitutional issue; it went back to the states being able to regulate alcohol. My husband came home from work one day and said, "Juanita is in the Financial Times." After the groundwork was laid, big-gun lawyers came down from New York to take her out to lunch. They wanted to take on the case. She said, "My lawyer was good enough for me when you people didn't know who I was, and he's going with me to the Supreme Court." He did, and they won. She died about a year after case was won.

Harig: Larry, what suggested your book to you? What research do you do to bring your characters to the page?

Goldstone: Research? It's fiction.

I'd written six books with my wife. Many of them had an element of the tension of empiricism in conflict with theology or religion. There was a common pattern, where empiricism confronted religious dogma, and empiricism gradually won out, sometimes after considerable hardship.

The early 1500's was a time of great purity in religious interpretation of empirical matters. Pope Leo was confronted with the problem that the calendar was off. Copernicus was called in about 1516; he told Pope Leo that it might have something to do with the Sun. Pope Leo was interested, but he was too busy building St. Peters'. He started indulgences to help pay for it; that caused Martin Luther to post his 95 theses, and Leo quickly lost his astronomy bug.

Copernicus went off to Poland and continued to work on his theory. He knew he was in a delicate area. Thomas Aquinas had incorporated Aristotle's thinking into Catholicism. He made Earth the center of the Universe because it seemed reasonable that, since man was the center of God's attention, man's home should be the center of the Universe.

So I thought, okay, what happens if people, kind of, get wind of it? That's how I got the germ. Then I got to bring in all the interesting characters, Servitus, Rabelais, and others. It's delicate, because you want the facts to be consistent with history, but it's fun because you get to invent facts and dialogue also. It was great fodder for a story, if you can hold it together.

Harig: Lou, you've written a number of stories about science and detective work in history. Now you have this character, Vidocq, who invented forensics and applied scientific methods to his work. Did he, like

Copernicus, encounter skepticism about his methods, and was he always a detective?

Bayard: Yes, he did encounter skepticism.

Your second question was very delicately phrased. Vidocq earlier was a convict. He escaped from many French prisons. He worked his way back to Paris; he was tired of running; he was being blackmailed by many of his former compatriots including his ex-wife, and he volunteered to work for the police as an informant. He went back to prison as a spy, and he was so successful, he worked his way up the chain of command. Within a year or two, crime in Paris was down. He founded the first private detective agency, which was a model for Pinkertons. Even more controversial: he staffed it with ex-cons, like himself. He was featured in works by Victor Hugo and Honoré de Balzac. Dickens and Melville alluded to him. Hugo divided him in two; he was a rich enough character for two characters.

Without him, I'm not sure modern detective work or detective fiction would be the same. I'm not sure we would have Sherlock Holmes.

Harig: When you are stuck, whom do you turn to?

Goldstone: On a technical matter, I turn to experts. In *Anatomy of Deception*, I got a referral from my gastroenterologist, who referred me to a man who had studied with one of my characters. With the 16th century, you can't do that. Mostly, the research is where I turn. Ptolemy and Copernicus have been extensively translated into English.

Crosby: The short answer is, I turn to experts. I contact the Fairfax County Police. Juanita was hard to get to; she did not use email; she did not have an answering machine. I'm always hoping for one expert who has a sense of whimsy who will tell you how to kill people. Once when I tried that, I was lucky I did not get turned in to Homeland Security, before the police found I was a writer.

Bayard: At the risk of coming off as lower class, I do a lot of research on Google. I found an extensive history of Vidocq there, which I later learned was about half incorrect. But, as a novelist, I feel free to make stuff up.

I got a question once from a copy editor who wanted the "scholarly citations" regarding a French psychologist from the early 18th century. I said, "There are none, because I made him up."

Readers go out of the way to tell us all the things we did wrong. I'm sure we all have experiences with people who come to us with great details about what we did wrong. I think of them as people with lots of cats. One

told me that I should know that poinsettias were not in English drawing rooms in 1842. I did know, but I'm a whore for a good detail. I feel that, as a historical novelist, I have a duty to err on the side of the story.

Cameron: I ran into a similar thing. I was asked to write a werewolf story for Christmas. I thought, "Okay, to the reference books." It took me a good ten minutes to think, "Wait a minute, this is fiction!" There is an extensive canon on werewolves and vampires, but you don't have to read it.

I was asked by the *Boston Noir* editor Dennis Lehane if I'd like to contribute a story. I said, "Oh my God, yes, please." But I didn't want to sound like I was following a formula for writing noir. I set it in 1740 in Boston, on the wharves. It had many of the conventions, such as an embattled young woman with no one to protect her. I deliberately did not read much about how to write noir. When I finished, I felt, "Okay, it's noir, but it's my noir." My academic training taught me to value accuracy. It was a hurdle for me, then, to learn that, when I'm stuck, I can just make something up.

Goldstone: The Amazon review is the bane of modern writer. One knocked me down two stars because I had the potato in Europe 20 years before it happened. And it wasn't like I made it a French fry.

Harig: Okay, final question: What are you working on now?

Cameron: I'm taking the idea that archeologists have traits and skills in common, and updating it. I'm working on an espionage novel. Ellen [Crosby] has helped me. It's been a lot of fun, learning to be a spy. I'm learning gunplay. Hopefully, it will go to a smart, savvy editor. Also, three short stories, one about my Fangborn vampires and werewolves, and two noir.

Bayard: I have a book coming out called the *School of Night*. It's set partly in Elizabethan England and partly in modern Washington. The School of Night was a group of Elizabethan scholars who were rumored to dabble in dark arts. It included Christopher Marlowe and Walter Raleigh. Actually, the hero of the book is a man named Thomas Herriot, who, unfortunately, did not leave many papers. We are still trying to figure out what he knew and when he knew it. He drew a picture of the moon before Galileo. He knew of the law of refraction. He was encouraged to keep quiet, like Galileo.

Then, the next book is about sainthood in the Catholic Church. It's about the whole business of confirming sainthood, which is an interesting,

complicated process. [Here, Mr. Goldstone quietly advised Mr. Bayard to get an unlisted phone number.]

Crosby: I just turned in my sixth book in my wine country series. I just got it back. I'll be doing revisions over Christmas. I'm not supposed to talk about it yet. There are two more in the making.

I have two publishers, Scribners, for hardcover, and Pocket, for paperback. They are both part of Simon and Schuster, but they are completely different companies. The illustration Scribners put in the hardcover catalog is an elegant thing, with a classy etching of F. Scott Fitzgerald, done for his 100th birthday. The Pocket illustration is of a swinging chick in a bikini on a surfboard in the Keys. I am very impressed that there can be such radically different icons associated with these two presentations of the same book.

Goldstone: I have a book coming out in February called *Inherently Unequal*. It's about the shameful record of the Supreme Court in civil rights cases from 1865 to 1903. That's my day job, the Constitution. I'm finishing another thriller about when heroin was first marketed as a cough medicine for children.

But what I am really working on is a book about my kid's piano teacher. One day, this woman, Vernona Gomez by name, showed up for a recital in a Yankees hat. "What's she doing in a Yankees hat?" I asked. Another parent said, "Do you know who that is? That's Lefty Gomez's daughter."

Years went by. One day, she called. "Can I come over?" "Yes."

[She brought over her material. She was working on a book and she had interviews with people who didn't give interviews. Mr. Goldstone referred her to his agent. Against his wife's advice, he declined to get involved himself, at that time. Six months later, the agent was burned out on the project. Gomez's son, a lawyer, had "completely obnoxed" the agent. Goldstone called and begged the agent to do it. The agent said, "I'll do it if you'll do it." So Goldstone is doing it, with Ms. Gomez.]

It's an unbelievable trove of material of an American Odyssey. Her father was best friends with Babe Ruth. He was Joe DiMaggio's roommate for seven years. This guy grew up dirt poor. The day Castro marched into Havana, Lefty was at Ernest Hemingway's house with an invalid passport. He'd been asked to go down there by John Foster Dulles after Nixon had been spat on in South America. Hemingway sent him to the Hotel with instructions to stay inside. The Castro people weren't going to let

anybody out without a valid passport. They found out who he was and Fidel Castro gave permission for him to leave.

Lefty, An American Odyssey, will be out in 2012.

Harig: That's it for the formal program. Any questions from the audience?

Question 1: You all have such breadth. How do you find the time? Do you all have day jobs?

Cameron: I just stay in my pajamas for an extra hour. I can't do anything else in pajamas, and I'm comfortable working that way, and I built on my day job that way. I'm a full-time writer now, I'm a recovering archeologist. You never get over that completely. Our vacations are all about broken things (artifacts). It's more fun when you can devote your whole time to a project.

Bayard: Stealing time is almost the writer's vocation. I used to write for nonprofit groups and others. I knew I was becoming successful when I found I could carve out two or three hours. Now, it is close to my day job. Writers, all of us here, have so many pins in the air, we are quite busy. And there is nothing more depressed than a writer between books.

Crosby: I worked as an economist on Capitol Hill. Then my husband got posted to Switzerland. I thought I'd work, but couldn't get a work permit. We went to Moscow, and there I gravitated toward journalism, which is hard to sell as a free-lance. Then I turned to nonfiction, which is better. It is full time; I have a book a year. My husband says he had no idea our lives were going to be like this. Fortunately, we don't live on what I make. He brings home the good paycheck.

Goldstone: I teach at a local community college. I write for my work. Writing doesn't pay terribly well. You get regular advances, and sometimes you score, but usually not. It's like the old garment center joke – lose a little on every garment, but make it up in volume.

You have to need to write. If you don't have the need, the business will just chew you up.

[The writers agreed that they need to have more than one project going. If one stalls, they can keep going on others.]

Question 2: How difficult is it to develop the conversation that goes on between characters within the plot line?

Goldstone: My dialogue works best when I am a reporter and when I am "watching." With experience, you develop an ear and an eye. You "hear"

the characters; you "see" the scenes. When the characters sound tinny, you know you are off. You feel it. You change it.

Bayard: There are perils in writing historical fiction. I started *School of Night* in Elizabethan, and I found I hated it. It sounded too stilted. I had to create a new style of dialogue that was more modern but with Elizabethan style touches. That seems to work better.

The second peril is making your characters mouthpieces for your research. You are tempted to teach the reader everything you learned about Grecian sewers. If you sprinkle too many historical facts into the dialogue, the characters don't seem real.

Henry James said there was no such thing as a good historical novel. You are forcing them to say things they would never say. But I think there is a way of working it, and it does require an ear.

Crosby: I was in radio, and I read all my books out loud. I usually read with my cat, who is pretty discerning and critical. I think that's why all my books are unabridged audio books. You catch all the little words that don't work.

Cameron: I do that, too. I read them to my husband. Historical facts? You don't want to put in all the tidbits. You have to develop a feel for "just enough." Paring it down between a dissertation and dialogue between criminals, that takes some work.

Question 3: How do you deal with the perceptions and misperceptions of your audience?

Crosby: The greatest one I deal with is the assumption that wine is not made in Virginia. That actually has been kind of fun. I travel a lot, in California, especially, they are surprised that people make wine in Virginia. It is a pleasure to educate them.

Goldstone: In books on the 15th century, you don't find much of that. Few people know much about the 15th century. In the end, you trust your research. You've done the reading; the critics are usually less well informed. The overly particular criticisms are often from people who want to justify not liking the book.

You need to accept that, no matter how good a book is, not everybody will like it.

Bayard: Writing about Tiny Tim, I was writing about a character I loathed. My purpose was to turn him into a character I liked. When I wrote

about Poe, it was about a period of his life few people know about, when he was a cadet at West Point. There are many myths about Poe, for example, that he was a drug addict. There is no evidence to support that.

I am reminded of the John Ford line, in "Liberty Valance": when the myths and the truth conflict, publish the myth. I guess we just create our own new myths.

Cameron: It usually isn't a problem with the archeologists. But I had a character once who was an Army brat. A real Army brat thought I hit a chord exactly wrong. I haven't had people call me out on having vampires cure people. I've cast vampires as sort of misunderstood superheroes. So far, I'm getting away with it.

I got a nice note from the Massachusetts Office of Historic Preservation, from the state archeologist. She was enthused about how I had presented women in historical settings, running pubs, getting beaten by their husbands. She had also deduced that must be true.

Archeologists often tell me they read my books because they are just like their own lives. I say, "I'm so sorry!"

People often want my characters to be just like them. I find that very funny.

Harig: Thanks to everybody for coming.

Peg Kay recalled one of the high points from the program of the previous year: Donna Andrews doing a remarkably animated imitation of a Penguin in Heat. Cameron remarked that she had been present at another penguin exhibit when Andrews recalled that eponymous penguin. [*vide* Donna Andrews' *The Penguin Who Knew Too Much*]

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Editor's Comments

July 21, 2011 marked a bittersweet moment in NASA's space program; namely, the end of the shuttle program. When Atlantis touched down at NASA's Kennedy Space Center, many paused to wonder what the future holds for space exploration and uncovering the mysteries of our solar system. This 30-year program has changed the way the public views space, and served as a catalyst for many young, aspiring scientists.

Although to many this was a sad moment in history, the end of the shuttle program is not the end of space exploration as a whole. Just 18 days after Atlantis touched down, the spacecraft Juno was launched on its mission to explore Jupiter, and other missions are approaching. In addition to these, we have countless scientists using advanced technology and methodology here on Earth to study our solar system.

In recognition of this, this issue of the Journal celebrates the wonders of astronomy, and discusses some of what we know, and in doing so demonstrates how much left there is to find out. Sethanne Howard provides a series of papers discussing black holes, dark matter, and the cosmic distance ladder. I hope that you enjoy immersing yourself in topics that we often hear about, but may not really *know* about.

Following these, we have included a summary of our Annual Awards Banquet, held on May 12, 2011. It was a great night. Mr. Sam Kean, author of *The Disappearing Spoon*, provided our keynote address and was a great success. We introduced the incoming board and said farewell and thank you to our outgoing members. And of course, we recognized the contributions of scientists in a variety of disciplines through our awards presentation. Thank you to the Awards Committee for your effort. We look forward to next year!

Jacqueline Maffucci
Editor, The Journal of the Washington Academy of Sciences

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Black Holes Can Dance

Sethanne Howard

USNO, retired

Abstract

This is the story of black holes seen from one astronomer's perspective. Although some very technical information is included, the intent is to review some information about this odd piece of nature.

Introduction

SIMPLY PUT, A *BLACK HOLE* [i] is a region of space from which nothing, not even light, can escape. It is the result of the deformation of space-time caused by a *very* compact mass – a lot of mass in a teeny (actually zero) volume. Around the black hole there is an undetectable surface (called the event horizon) which marks the point of no return. Once inside nothing can escape. A black hole is called "black" because it absorbs all the light that hits it, reflecting nothing, just like a perfect blackbody in thermodynamics. We cannot see, hear, smell, touch, or taste it.

Now that we know that much, let us look at some history.

Newton's universe did not include black holes. I shall start there, and assume we know the basics of Newton's laws.

Even though Newton did not discuss black holes, the idea of them has been around for some time.

The idea of a body so massive that even light could not escape was first put forward by geologist John Michell[ii] in a letter written to Henry Cavendish[iii] in 1783 to the Royal Society:[iv]

> If the semi-diameter of a sphere of the same density as the Sun were to exceed that of the Sun in the proportion of 500 to 1, a body falling from an infinite height towards it would have acquired at its surface greater velocity than that of light, and consequently supposing light to be attracted by the same force in proportion to its *vis inertiae*, with other bodies, all light emitted from such a body would be made to return towards it by its own proper gravity.

In 1796, mathematician Pierre-Simon Laplace[v] promoted the same idea in the first and second editions of his book *Exposition du système du Monde* (it was removed from later editions). He pointed out that there could be massive stars whose gravity is so great that not even light could escape from their surface.

Such dark objects were ignored until the 20th century, since it was not understood how gravity could influence a massless wave such as light.

It took Albert Einstein (and others) to show that gravity can influence light. First with his Special Theory of Relativity and second with his General Theory of Relativity he proved that gravity does influence the motion of light. According to Einstein, space warps when close to matter. The more matter there is, the more space warps. The description of the curvature (warping) of space is the mathematically complicated part of general relativity. It involves tensor calculus and *metrics*. In mathematics, the word metric refers to a fairly general function which defines the 'distance' between elements in a set. I tend to think of a metric as a bendable and twistable ruler that allows one to measure intervals (distances) between two events. **Keep the concept of a metric in mind**.

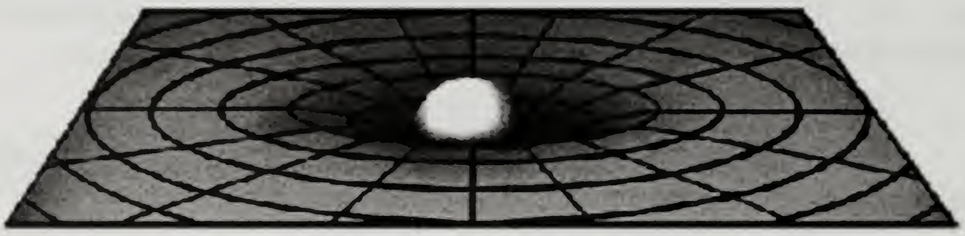


Figure 1. The curvature of space caused by a massive object.

Figure 1 represents a two-dimensional slice through three-dimensional space showing the curvature of space produced by a spherical object, *e.g.*, the Sun. Einstein's view is that the planets follow the curvature of space around the Sun (and produce a tiny amount of curvature themselves).

Metrics and the Special Theory of Relativity

The Special Theory of Relativity (STR) has as its basic premise that light moves at a uniform speed, c = 300,000 km/s, in all frames of reference. This results in setting the speed of light as the absolute speed limit in the universe and also produces the famous relationship between mass and energy, $E = mc^2$.

In Newtonian flat space (the kind we are familiar with) the metric that defines distance is:

$$ds^2 = dx^2 + dy^2 + dz^2$$

where *ds* is the distance and (*x*, *y*, *z*) are the spatial coordinates (remember your high school geometry). Strictly speaking this is the line element, not the metric. For the purpose here, I use the words interchangeably.

In STR the metric becomes a combination of time and space:

$$ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2 .$$

In spherical coordinates it is:

$$ds^2 = -c^2dt^2 + dr^2 + r^2d\theta^2 + r^2 \sin^2 \theta d\phi^2$$

or more concisely

$$ds^2 = -c^2dt^2 + dr^2 + r^2d\Omega^2 .$$

It is from STR that we get the term *space-time* – space and time forming a single continuum, *ds*. Note the difference between this metric and the metric of Newton's world. In Einstein's world the distance (interval) between two events depends on the time *and* space intertwined.

The General Theory of Relativity

As useful as Newtonian mechanics may be, it is merely a limiting case of relativistic mechanics. The General Theory of Relativity (GTR) is the geometric theory of gravitation published by Albert Einstein in 1916. It is the current description of gravitation in modern physics.

We need GTR because **black holes require GTR for explanation**, yet GTR is a difficult subject no matter how one looks at it. This is what the basic equation of GTR looks like:

$$G_\mu^\nu + \Lambda g_\mu^\nu = \frac{8\pi G}{c^4} T_\mu^\nu$$

where G_μ^ν is the Einstein tensor,[vi] Λ is the cosmological constant,[vii] g_μ^ν is the metric tensor,[viii] and T_μ^ν is the stress-energy tensor. This equation describes the interaction of gravitation as a result of space-time being curved by matter and energy. The left side of the equation contains the information about how space is curved (the geometry), and the right side contains the information about the location and motion of the matter (the

dynamics). When fully written out, the equations are a system of coupled, nonlinear, hyperbolic-elliptic partial differential equations.

You may now forget these equations because they are not necessary for the rest of the paper except to say that solutions to these equations under certain conditions give us black holes.

Two Metrics That Define Black Holes

Solutions to the Einstein's GTR equations are *metrics of space-time* – ways to describe gravity and mass interacting with each other. **The metric is the fundamental object of study for black holes.**

The first solution came in 1916 when astronomer Karl Schwarzschild (1873-1916) solved the equations for the particular case of a non-rotating spherically symmetric point mass.[ix,x] This point mass solution (where all the mass is concentrated into a single point) describes a black hole.

The metric solution for the point mass was named after Schwarzschild – the *Schwarzschild metric* defines the space-time environment near a black hole of mass *m*. The metric is spherically symmetric and non-rotating (no angular momentum). This is the simplest type of black hole. The metric only looks complicated:

$$c^2 d\tau^2 = \left(1 - \frac{2Gm}{c^2 r}\right) c^2 dt^2 - \left(1 - \frac{2Gm}{c^2 r}\right)^{-1} dr^2 - r^2 d\Omega^2 .$$

The quantity $\left(1 - \frac{2Gm}{c^2 r}\right)$ appears twice. It is there so that in the limit of large r and small m the metric reduces to the Newtonian gravitational field around a point mass. At $r = 0$ there is a true singularity.[xi] Note, however, the possibility of infinity when $r = 2Gm/c^2$. This particular value for r is called the *Schwarzschild radius* (r_s), a special radius that is quite useful, as we shall see.[xii]

It took some time for the next black hole solution to appear; however, in 1963, mathematician Roy Kerr found the exact solution for a rotating black hole. The more complicated *Kerr metric* for a black hole with angular momentum J is:

$$c^2 d\tau^2 = \left(1 - \frac{r_s r}{\rho^2}\right) c^2 dt^2 - \frac{\rho^2}{\Delta} dr^2 - \rho^2 d\theta^2 - \left(r^2 + \alpha^2 + \frac{r_s r \alpha^2}{\rho^2} \sin^2\theta\right) \sin^2\theta \, d\phi^2 + \frac{2 r_s r \alpha \sin^2\theta}{\rho^2} c\, dr\, d\phi ,$$

where r_s is the Schwarzschild radius, and the scale lengths α, ρ, and Δ are:

$$\alpha = \frac{J}{mc},$$
$$\rho^2 = r^2 + \alpha^2 \cos^2 \theta, \text{ and}$$
$$\Delta = r^2 - r_s r + \alpha^2.$$

At $r = 0$ there is the true singularity, however, the Kerr metric has two values for r where it appears to be singular: r_{inner} and r_{outer}. The inner surface occurs where the purely radial component of the metric goes to infinity:

$$r_{inner} = \frac{r_s + \sqrt{r_s^2 - 4\alpha^2}}{2}.$$

The other singularity occurs where the purely temporal component of the metric changes sign from positive to negative:

$$r_{outer} = \frac{r_s + \sqrt{r_s^2 - 4\alpha^2 \cos^2 \theta}}{2}.$$

The Kerr black hole, therefore, has two special radii with the *ergosphere* (sphere of influence of the black hole – more on it later) between them. The outer surface is also called the static limit. The inner surface is also called the event horizon.

Note something important. The parameter t (time) does not occur in the right side of either metric. **Time stops at a black hole**.

So by the 1960s scientists could describe the enivironment around stationary,[xiii] non-rotating, and rotating black holes.[xiv] Given these metrics, people got to work on the dynamics of black holes.

The Four Laws

By the 1970s research by many people led to the formation of the four laws of black hole dynamics. These laws describe the behavior of a black hole in close analogy to the laws of thermodynamics by relating mass to energy, surface area to entropy, and surface gravity to temperature. The analogy was completed when Stephen Hawking, in 1973, showed that quantum field theory predicts that black holes radiate (*Hawking radiation*, see the section on this) like a blackbody with a temperature proportional to the surface gravity of the black hole.[xv] Further description of the four laws is highly mathematical and beyond the scope of this paper.

Despite these laws we still cannot describe a black hole all the way to $r = 0$. That will require combining quantum and gravitational effects into a single theory, although the single theory does have a name: quantum gravity. This is an area of active research.

However, the four laws led to a definition of what one *can* measure in a black hole.

Black Holes Have No Hair

The four laws led to the 'no-hair theorem' – black holes have no hair. This means that a stationary black hole is completely described by only three things: its *mass*, *angular momentum*, and *electric charge*. There is no other way to 'grab' onto (measure) a black hole. These properties are special because they and only they are detectable from outside the black hole. For example, a charged black hole repels other like charges just like any other charged object. Why these three? The reason is mathematical; these are unique, conserved imprints in the external fields of the black hole (conserved Gaussian flux intervals).

Theoretically a black hole may possess electric charge but it would quickly attract charge of the opposite sign and become neutral. The net result is that any realistic black hole would tend to exhibit zero charge.

I shall discuss two types of black holes: one defined by the Schwarzschild metric and one defined by the Kerr metric. There are others, but they are quite specialized. In fact, there are four basic types:

	Non-rotating	Rotating
No charge	Schwarzschild	Kerr
Charged	Reissner-Nordström	Kerr-Newman

When most people think of a black hole, it is usually the Schwarzschild black hole. So I shall discuss this one first.

The Particulars of the Schwarzschild Black Hole

The Schwarzschild black hole is stationary (not moving through space) with zero charge and is non-rotating. It is 'dead' in the sense that one can never extract from it any of its mass-energy. No information can ever come from a Schwarzschild black hole. This means it is stable against a perturbation (*e.g.*, a kick), were you so inclined.

At the Schwarzschild radius, r_s, some of the terms in the metric apparently become infinite. This is not a true singularity.[xvi] It is due to the choice of spherical coordinates; however, it does have a physical effect.

In 1958 physicist David Finkelstein[xvii] identified the Schwarzschild surface $r_s = 2Gm/c^2$ as an *event horizon*, "a perfect unidirectional membrane: causal influences can cross it in only one direction." That means it is a one way gate. Things go in and do not come out. At the rim of the event horizon one must travel at the speed of light just to stay in place. Once inside the event horizon the radial coordinate 'evaporates' because there can be *no* spatial direction that will lead back to the outside. **Once inside the event horizon escape is not possible**.

The 'size' of a black hole, as determined by the radius of its event horizon (Schwarzschild radius), is roughly proportional to its mass *M*:

$$r_s = \frac{2GM}{c^2} \approx 2.95 \frac{M}{M_\odot} \text{km} .$$

where $M_\odot$ is the mass of the Sun. This relation is exact only for Schwarzschild black holes; for more general black holes it can differ up to a factor of two. Table I shows this relation for some common objects.

Table I. The Schwarzschild radius for different sized objects.

Object	$r_{\text{Schwarzschild}}$
Earth	1 cm
Jupiter	3 meters
Sun	3 kilometers
3 solar-mass star	9 kilometers
3000 solar masses	9000 kilometers

So, for the Earth to become a black hole, all its mass must be consolidated within a sphere of a one centimeter radius. This is highly unlikely.

Figure 2 illustrates how space-time curves about a Schwarzschild black hole. At the center of a black hole lies a true gravitational singularity.[xviii] At $r = 0$ the space-time curvature becomes infinite. For a non-rotating black hole this region takes the shape of a single point. For a rotating (Kerr) black hole it is smeared out to form a ring singularity lying in the plane of rotation. In both cases the singular region has zero volume. The singular region can thus be thought of as having infinite density. All this really means is that we do not understand what happens at the singularity.

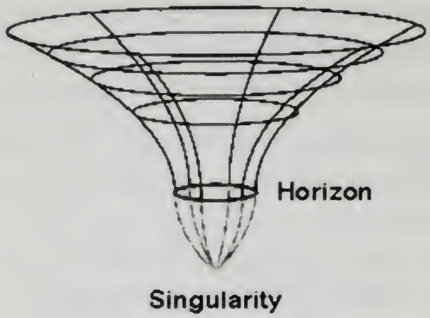


Figure 2. Curved space-time around a Schwarzschild black hole.

Does this mean that gravity is somehow different around a black hole? It is misleading to say that black holes have 'stronger' gravity than other masses. Black hole or not, the curvature one feels depends strictly on the mass of the object and the distance one is from that mass, not whether the object is a black hole. When that mass is concentrated in a small volume, however, one can get closer to the mass than otherwise is the case. This may be why one thinks gravity is stronger around a black hole. It is actually the field density that is greater. The gravitational field density close to an Earth mass compressed within a 1 cm radius is much higher than the density around an Earth mass with its current radius. A lot of mass in a very tiny space can strongly warp the space nearby – tiny and nearby being the key words.

So, if the Sun became a black hole, would we on Earth notice? We would miss the sunlight and die (so we would notice), but the gravitational effect on Earth would be what it always was. The mass of the Sun has not changed (even though it occupies a smaller volume); the Earth's distance from the Sun has not changed; therefore, the Earth feels the same effect and continues to orbit the black hole Sun.

This leads me to the next point.

Black holes are *not* cosmic vacuum cleaners. They do not zoom around space sucking up matter. The black hole Sun will not scoop up the Earth. Far from the Sun there is no unusual gravitational influence. Only within a few Schwarzschild radii is there a significant effect. Black holes *can* accrete matter but only when the matter is quite close. In fact, scientists believe black holes are surrounded by *accretion disks* – a disk of accreting matter (usually gaseous) orbiting the central object.

Now that we know a bit more about them, let us see how they are made.

Making a Black Hole

There are two classes of black holes: (1) a stellar mass black hole, and (2) a super massive black hole.

Class (1) happens when a heavyweight star reaches the end of its life. One way to classify stars is by their birth weight. Heavyweight stars are born with more than 30 solar masses to their credit. Most of a star's life is spent maintaining a balance between two forces: radiation pressure from the nuclear fusion in the core that pushes outward; and the gravitational force trying to compress the gas inward. Ultimately a heavyweight star will, as all stars do, consume all its nuclear fuel. It can then no longer support itself against a subsequent gravitational collapse. If it fails to eject its excess mass in the collapse process then nothing can stop the stellar remnant from collapsing toward a point – forming a black hole. This collapse happens in milliseconds – the star winks out. Our Sun (a lightweight star) is not massive enough to end its life this way. It will end as a white dwarf. A middleweight star (between 6 and 30 solar masses) will explode as a supernova and end as a neutron star.

Most stars are not perfectly spherical and have a lot of angular momentum, so the gravitational collapse produces a black hole more in line with a Kerr black hole than a Schwarzschild black hole.

Class (2) is thought to lurk in the centers of most galaxies. A super massive black hole contains thousands to millions of solar masses. Once a super massive black hole has formed, it can continue to grow by absorbing additional matter. One model for the formation of super massive black holes is by slow accretion of matter onto a stellar mass black hole. Another model involves a large gas cloud collapsing into a relativistic star of perhaps a hundred thousand solar masses or larger. The star would then become unstable and may collapse directly into a black hole without a supernova explosion. Super massive black holes have properties which distinguish them from stellar mass black holes:

- The average density of a super massive black hole (defined as the mass divided by the volume within its Schwarzschild radius) can be as low as the density of water for very high mass black holes.
- The tidal forces in the vicinity of the event horizon are significantly weaker than the tidal forces around a stellar mass black hole.

Astronomers think the universe is littered with black holes, that they are not rare at all. In addition to the stellar type they think that nearly every galaxy has a central super massive black hole. What if we could visit one?

A Trip to a Black Hole

An observer falling into a Schwarzschild black hole cannot avoid the singularity at $r = 0$. Any attempt to do so will only shorten the time taken to get there. As the traveler spirals in, there is a last stable orbit[xix] at a distance of $3r_s$. Continuing inward, the traveler crosses the event horizon. At the singularity the traveler is crushed to infinite density and its mass added to the black hole. Before that happens, though, it will have been torn apart by the tidal forces in a process sometimes referred to as *spaghettification* (I did not make that up) or the *tube-of-toothpaste-effect.*

To describe this in more detail, assume there are two astronauts, a smart one and a dumb one. Their spaceship arrives near a 3 solar mass black hole (r_s = 9 km). The smart astronaut stays in the spaceship. The dumb astronaut jumps toward the black hole. Let us pick up the action 900 km away ($100r_s$).

At this distance of 100 r_s from the black hole the dumb astronaut is torn apart due to the tidal effect of gravity, and the story ends. For comparison, the gravity tide on a human (head to toe) on the Earth's surface is about one millionth of a *g*.

For a 3 solar mass black hole the tidal force of the black hole is shown in Table II. Remember that tidal forces go as $1/r^3$, so the tides quickly become fatal as one approaches the black hole.

Table II. Tidal force in *g*'s versus distance in km from a 3 solar mass black hole.

Distance (km)	Force (g's)
6400	0.5
2000	18
1000	144
100	150,000
10	150,000,000

For the purposes of argument, though, assume the dumb astronaut is 'stretchable.' Then as he falls, toe first, his toes are closer to the upcoming event horizon than his head. The gravity tides between his toes and head cause his toes to travel faster than his head. He stretches. The closer he gets, the more he stretches. Simultaneously he is squeezed into regions of ever decreasing circumference. He gets longer and thinner, forming dumb astronaut spaghetti strings.

As he travels toward the event horizon he may notice nothing out of the ordinary, except an inability to steer himself in any but one direction – which is toward the "invisible" hole. He will never know when he has crossed the event horizon were it not for the increased tidal tugging that draws his body longer and longer, squeezing in from the sides (actually at this point he is a set of disconnected atoms, zooming along all in a line). Just before he reaches the event horizon, each piece of him emits high energy radiation (x-rays) as that piece disappears forever. He winks out of sight with a puff of radiation. It is a rather spectacular way to die.

And it is a wonderful way to garner energy. The efficiency of energy generation near a stationary black hole is about 6%. Near a rotating black hole this reaches about 30% efficiency. This is a staggering amount. It is the best return of energy known. Compare the efficiency of combustion on Earth which is only about 10^{-8}. The efficiency of nuclear burning (in a star) is about 7×10^{-3}.

A visit to a super massive black hole is less dramatic although it ends the same way. If the mass of the black hole is about 30,000 solar masses then the dumb astronaut will not be torn apart by tidal forces at the event horizon. This will wait until he is much deeper inside. Of course, once he crosses the event horizon he cannot return or send messages. Although he may survive those tidal forces, the high energy radiation (all those x-rays and gamma rays lurking at the event horizon) will fry him.

One can calculate how long the dumb astronaut spaghetti string will "live" once inside the event horizon. No matter how he approaches a black hole of mass M, once inside the event horizon he will be killed at the $r = 0$ singularity in a proper time of about $1.54 \times 10^{-5}\ M/M_\odot$ seconds. So for a 10 solar mass black hole, he will die in 154×10^{-5} sec (0.00154 sec). One way or another, **the dumb astronaut will not survive the trip**.

Time Dilation

If the dumb astronaut carries a flashlight and points it back at the smart astronaut, and flashes it in a regular pattern, what will the smart astronaut see? She will see the flashes get further and further apart eventually slowing down to a stop (after an infinite amount of time). The GTR predicts that time will slow in the presence of matter – this is called time dilation. It is not just clocks by the way, all physical processes, including clocks ticking (however they measure their ticks), hearts beating, aging, *etc.*, must slow down, but the only one who notices is the distant timekeeper. This is not an imaginary effect. When transporting

atomic clocks on the Earth, one must correct for the GTR effects of the Earth on the moving clock.

Gravitational Redshift

In addition to the slow down of time, the light she sees is redshifted more and more as the dumb astronaut gets closer to the event horizon. This is not a Doppler shift. Light loses energy when escaping from a gravitational field. Because the energy of light is proportional to its frequency, a shift toward lower energy represents a shift toward the red for visible light. This gravitational redshift was first observed in the spectra of dense white dwarf stars, whose light is redshifted by about 1Å. Gravitational redshift was experimentally verified on Earth by the Pound–Rebka experiment of 1959.

Now that we know the dumb astronaut will not survive, is there a way we can we tell that he fell in?

Cosmic Censorship

When an object falls into a black hole, any and all information about the shape of the object or distribution of charge on it is evenly distributed along the horizon of the black hole, and is lost to outside observers. So not only does the dumb astronaut disintegrate, but also there is no way to determine that it was a dumb astronaut that fell in.

Because the black hole eventually achieves a stable state with only three measureable parameters (mass, charge, and angular momentum), there is no way to avoid losing information about the initial conditions. Nature puts a curtain around black holes so that we cannot see inside or know what happens inside – this cosmic censorship is complete. **There are no 'naked' singularities**. And the event horizon must be real, not complex.[xx] The information that is lost includes every quantity, including the total baryon number, lepton number, and all the other nearly conserved pseudo-charges of particle physics.

At least that was the state of the current thought until the 1970s. The physicist Stephen Hawking (author of *A Brief History of Time* and *The Universe in a Nutshell*) has long worked in theoretical cosmology. In 2009 he received the Presidential Medal of Freedom. He even played himself on *Star Trek*. I discuss one aspect of his work next.

Hawking Radiation

In 1974 Stephen Hawking realized that black holes are not absolutely black. There are quantum effects that allow black holes to emit blackbody radiation. The temperature of this radiation is inversely proportional to the black hole's mass; the tinier the black hole the higher the temperature of the radiation – called *Hawking radiation.*

Hawking radiation is due to particle/anti-particle pairs (*e.g.*, electron/positron) which are continuously created and annihilated in free space. When this pair creation happens near a black hole it is possible for one of the two particles to cross the event horizon before it meets and annihilates its partner. The other particle is then free to leave the scene, making the black hole appear to the outside world as a source of radiation. In other words, there is 'new' energy. So to satisfy energy conservation, the particle that fell in must have a negative energy (with respect to an observer far away from the black hole). Thus, the black hole loses mass, and, to an outside observer, it appears that the black hole has just emitted a particle. It takes energy to create new particles. This energy must come from the black hole. The black hole therefore decreases its mass as it radiates. Thus black holes will slowly evaporate.

A one solar mass black hole has a temperature of only 60 nanoKelvin (v-e-r-y cold); in fact, such a black hole would absorb far more cosmic microwave background radiation than it emits. Evaporation will take 10^{70} years. This is far longer than the age of the universe.

A smaller black hole of 4.5×10^{22} kg (about the mass of the Moon) would be in equilibrium at 2.7 K, absorbing as much radiation as it emits. Even smaller black holes would emit more than they absorb, and thereby lose mass.

For a miniature black hole – about 10^{12} kg mass which is the mass of a mountain – evaporation will take about as long as the universe is old. It is conceivable that conditions in the very earliest epochs of the universe might have been just right to compress pockets of matter into these miniature black holes. The Schwarzschild radius of such a black hole is about 10^{-15} m, comparable to the size of a subatomic particle. This begs the question how these teeny black holes got formed; however, at the end of its life, the mass of the tiny black hole becomes smaller and smaller, and hence its temperature tends towards infinity. The black hole ultimately disappears in an explosion. Fortunately (or unfortunately) current physics is unable to explain the last phases of the evaporation of the black hole.

Black Hole in a Bathtub

Recently scientists in Canada have measured the equivalent of Hawking radiation from a "bathtub black hole." In August 2010, the Canadian scientists announced[xxi] that they had made an event horizon in a water channel. They sent a steady flow of water in one direction. As it passed over the top of a piece of wood whittled in the shape of an airplane wing, the water traveled faster (aka Bernoulli). In the opposite direction, the group created water waves. When these waves approached the wing, where water was flowing faster, they slowed to a stop. Technically this bathtub version is a white hole, an inverted black hole that keeps waves out rather than bringing them in. But the white hole serves as an analog because it shares an important feature with astrophysical black holes — an imaginary boundary that emits an unusual kind of radiation. These laboratory emitters of Hawking type radiation share one required feature with their astrophysical counterparts — a point of no return, analogous to the black hole's event horizon. Both types have event horizons, so both ought to emit Hawking radiation. In fact, pairs of short-wavelength waves were created at the bathtub horizon and swept away, and the energy of these emitted waves matches what would be predicted from Hawking radiation around a real black hole.

This seems a bit forced to me.

Hawking radiation introduced a debate in cosmological circles. Is it consistent with the no hair theorem? This leads to a paradox.

The Paradox in Hawking Radiation

There is a paradox with Hawking radiation. From the no hair theorem, one expects the Hawking radiation to be completely independent of the material entering the black hole. All information is lost entering a black hole. Nevertheless, if the material entering the black hole were a pure quantum state, the transformation of that state into the mixed state of Hawking radiation would destroy information about the original quantum state. The rules of quantum mechanics say information is conserved in the wave function. The no hair theorem says the information is lost – a physical paradox.

Hawking remained convinced that the equations of black hole thermodynamics together with the *no-hair theorem* led to the conclusion that quantum information will be destroyed. This annoyed many physicists, notably John Preskill, who in 1997 bet Hawking and Kip Thorne that information was not lost in black holes. This led to the

Susskind-Hawking battle, where Leonard Susskind and Gerard't Hooft publicly declared war on Hawking's solution, with Susskind publishing a popular book about the debate in 2008 (*The Black Hole War: My battle with Stephen Hawking to make the world safe for quantum mechanics*). The book carefully notes that the war was purely a scientific one, and that at a personal level, the participants remained friends. The solution to the problem is the holographic principle (a property of quantum gravity combined with string theory). With this, as the title of an article puts it, "Susskind quashes Hawking in quarrel over quantum quandary."

In July 2005, Stephen Hawking announced a theory that quantum perturbations of the event horizon could allow information to escape from a black hole, which would resolve the information paradox. When announcing his result, Hawking also conceded the 1997 bet, paying Preskill with a baseball encyclopedia "from which information can be retrieved at will." However, Thorne remains unconvinced of Hawking's proof and declined to contribute to the award.

It does not end there. Roger Penrose advocates the Conformal Cyclic Cosmology (CCC) which critically depends on the condition that information is in fact lost in black holes. In CCC, the universe iterates through infinite cycles, with the future time-like infinity of each previous iteration being identified with the Big Bang singularity of the next. This CCC model might in future be tested experimentally by detailed analysis of the cosmic microwave background radiation (CMB): if true the CMB should exhibit circular patterns with slightly lower or slightly higher temperatures. In November 2010, R. Penrose and V. G. Gurzadyan announced they had found evidence of such circular patterns (Figure 3), in data from the Wilkinson Microwave Anisotropy Probe corroborated by data from the BOOMERanG experiment[xxii]. However, the statistical significance of the claimed detection has been questioned. Three groups have independently attempted to reproduce these results, and found that the detection of the concentric anomalies was not statistically significant. Stay tuned.

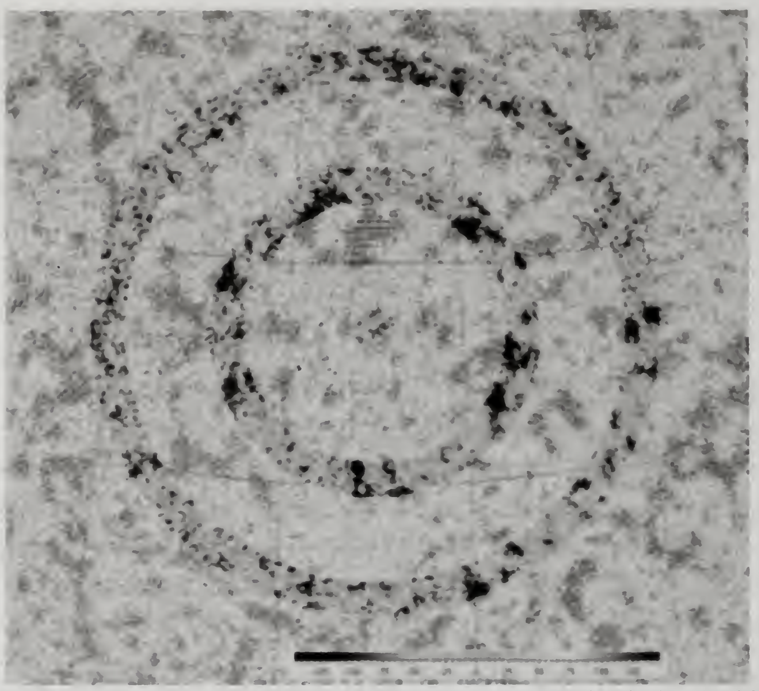


Figure 3. Possible circles in BOOMERanG data – the concentric circles are highlighted. The mottling represents the wrinkles in space-time of the cosmic microwave background.

The Particulars of the Kerr Black Hole

The other type of black hole I shall discuss is the Kerr black hole, which rotates (has angular momentum). Seen in cross-section, the Kerr black hole is oval-shaped, with the ergosphere extending farther into space at the black hole's equator than at its poles (Figure 4). The $r = 0$ singularity is a ring of zero volume.

The Kerr black hole is actually more significant than the Schwarzschild black hole because most black holes spin. Part of the mass is actually stored as rotational energy in the ergosphere (which means 'place where work can be done') and is, in theory, available for extraction since the mass has not yet crossed the event horizon. This type can inject energy into its surroundings – hence this type is 'live.'

Kerr space-time is what happens when a black hole has reached its final evolutionary state. Kerr space-time is time-independent, meaning that nothing in Kerr space-time changes over time. In effect, time stands still. Remember that the time parameter t does not appear in the right side of the Kerr metric. A black hole in such a state is essentially stationary.

Figure 4. Side view of a conceptual Kerr black hole.

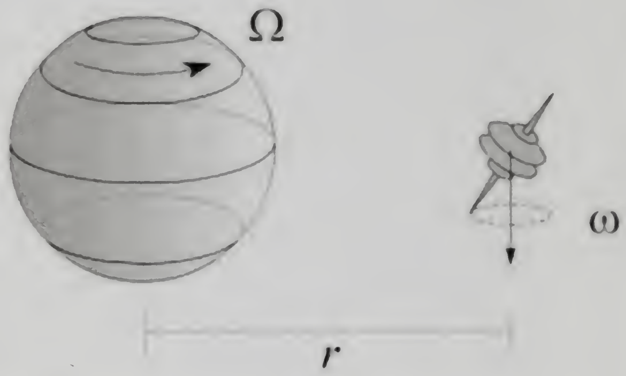
Frame Dragging

When the black hole is spinning it actually pulls the fabric of space-time around with it – an effect called frame dragging, also known as the *Lense-Thirring* effect. The rotation of the black hole or even the rotation of a very massive object will alter local space-time by dragging a nearby object out of position compared with the predictions of Newtonian physics. Frame dragging is like what happens if a bowling ball spins in a thick fluid such as molasses. As the ball spins, it pulls the molasses around itself. Anything stuck in the molasses will also move around the ball. This dragging happens in the ergosphere. The closer to the black hole the greater the dragging.

Inside the ergosphere (inside the static limit) nothing can stand still; therefore, particles falling within the ergosphere are forced to rotate and thereby gain energy. They *must* orbit in the same direction as the black hole rotates. So long as they are still outside the event horizon, they may, however, escape the black hole. The net process is that the rotating black hole emits energetic particles at the cost of its own total energy. The possibility of extracting spin energy from a rotating black hole was first proposed by the mathematician Roger Penrose in 1969.

The Earth is a very massive object; therefore, as the Earth rotates, it pulls space-time in its vicinity around itself. This action introduces a

precession on all gyroscopes in a stationary system surrounding the Earth (Figure 5). The predicted Lense-Thirring effect is small — about one part in a few trillion – yet measureable. A Foucault pendulum would have to oscillate for more than 16000 years to precess 1 degree.



$$\frac{\omega}{\Omega} = \frac{2}{3}\frac{r_s}{r}$$

Figure 5. The Earth rotating with angular velocity Ω; The gyroscope a distance *r* away precesses with angular velocity ω.

LAGEOS (Laser Geodynamics Satellites) are a series of scientific research satellites designed to provide an orbiting laser ranging benchmark for geodynamical studies of the Earth. The Lense-Thirring effect on LAGEOS due to the rotating Earth has been measured. The effect shifts the orbits of the satellites about 2 meters per year in the direction of rotation. The results are compatible with the predictions of GTR.

Another test of frame dragging is the Gravity Probe B satellite – launched in 2004 (now decommissioned) with a dual purpose: to measure the frame dragging of Earth, and to measure the geodetic effect – the amount by which the Earth warps the local space-time in which it resides. For Gravity Probe B, in polar orbit 642 km above the Earth, frame dragging causes its gyroscope spin axes to precess in the east-west direction by a mere 39 milliarcsec/yr. — an angle so tiny that it is equivalent to the average angular width of Pluto as seen from Earth.

Initial results from Gravity Probe B confirmed the expected geodetic effect to an accuracy of about 1%. In December 2008 NASA reported that the geodetic effect was confirmed to better than 0.5%. Unfortunately the expected frame-dragging effect was similar in

magnitude to the noise level. Work continues on the data to model and account for these sources of unintended signal, thus permitting extraction of the frame-dragging signal if it exists at the expected level. By August 2008 the uncertainty in the frame-dragging signal had been reduced to 15%. Final results are expected in 2011.

Many astrophysical objects, *e.g.* pulsars and black holes, emit jets of energy. These jets may also provide evidence for frame-dragging. Such jets are extremely powerful bursts of energy. Some of them extend huge distances into space. There are images of jets later in the paper (Figures 12, 13). These jets are tightly collimated flows of energy, collimated perhaps by the twisting of magnetic field lines by frame dragging.

The energy released in an astrophysical jet is overwhelmingly powerful – at the highest end of the electromagnetic spectrum – x-rays and gamma rays. A trip through a jet would quickly fry the traveler. Or is there a way to cut through space-time?

Shortcuts through Space – Wormholes?

If one can avoid the jet, perhaps one can escape to another universe. A wormhole is a hypothetical topological feature of space-time that would be, fundamentally, a "shortcut" through space-time. The physicist John Wheeler coined the term *wormhole* in 1957; however, in 1921, the mathematician Hermann Weyl already had proposed the wormhole theory.

There is no observational evidence for wormholes, but there are valid theoretical solutions to the equations of GTR which contain wormholes. These solutions say that it is theoretically possible to avoid the singularity at $r = 0$ and exit the black hole into a different space-time with the black hole acting as a wormhole.

For a simple explanation of a wormhole, consider space-time as a two-dimensional (2D) surface. If this surface is folded along a third dimension, it allows one to picture a wormhole "bridge." (Please note that this is merely a visualization to convey a structure existing in four or more dimensions). The parts of the wormhole could be higher-dimensional analogues for the parts of the curved 2D surface; for example, instead of mouths which are circular holes in a 2D plane, a real wormhole's mouths could be spheres in 3D space. A wormhole is, in theory, much like a tunnel with two ends each at separate points in space-time. Figure 6 illustrates a 2D wormhole.

Figure 6. A 2D representation of a wormhole.

The first type of wormhole solution discovered was the *Schwarzschild wormhole*. Technically the Schwarzschild metric has a negative square root as well as a positive square root solution for the geometry. The complete Schwarzschild geometry consists of a black hole, a white hole, and two universes connected at their event horizons by a wormhole. The negative square root solution inside the horizon represents a white hole. A white hole is a black hole running backwards in time. Just as black holes swallow things irretrievably, so also do white holes spit them out.[xxiii] The negative square root solution outside the event horizon represents another universe. The wormhole joining the two separate universes is known as the Einstein-Rosen bridge. Unfortunately it is impossible for a traveller to pass through this wormhole from one universe into the other. A traveller can pass through an event horizon only in one direction. First, the traveller must wait until the two white holes have merged, and their horizons meet. The traveller may then enter through one horizon. But having entered, the traveller cannot exit, either through that horizon or through the horizon on the other side. The fate of the traveller who ventures in is to die at the singularity which forms from the collapse of the wormhole.

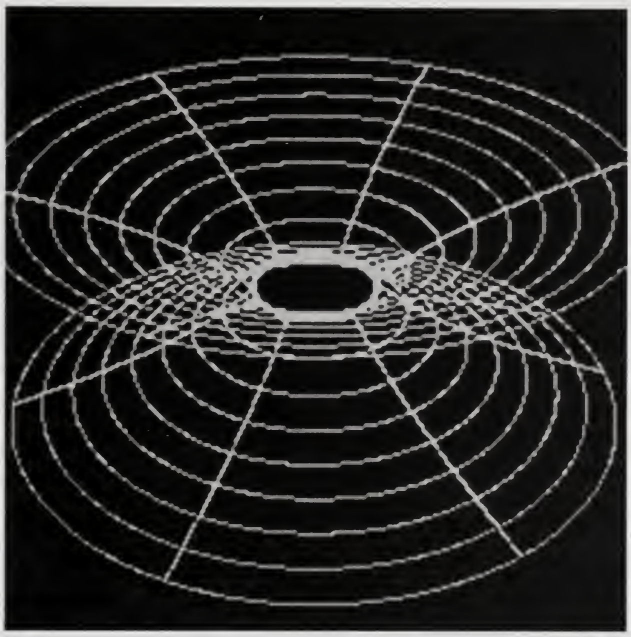


Figure 7. A 2D representation of a traversable wormhole.

Wormholes which could actually be crossed (Figure 7), known as *traversable wormholes*, would only be possible if exotic matter with negative energy density could be used to stabilize them (keep them from collapsing). Physicists have not found any natural process which would form a stable wormhole, although the quantum foam hypothesis (QFH) is sometimes used to suggest that tiny wormholes might appear and disappear spontaneously at the tiniest scale. Qualitatively QFH is described as subatomic space-time turbulence at extremely small distances of the order 10^{-35} meters. At such small scales of time and space the Heisenberg uncertainty principle allows particles and energy to come briefly into existence, and then annihilate, without violating conservation laws. However, without a theory of quantum gravity it is impossible to be certain what space-time would look like at these scales.

Finally, even if wormholes exist and are stable, they are quite unpleasant to travel through. Radiation that pours into the wormhole (from nearby stars, the cosmic microwave background, jets, *etc.*) gets blueshifted to very high frequencies, well into the high energy end of the spectrum. As you try to pass through the wormhole, you will get fried by these x-rays and gamma rays. So, at the moment, **space travel using wormholes is not possible.**

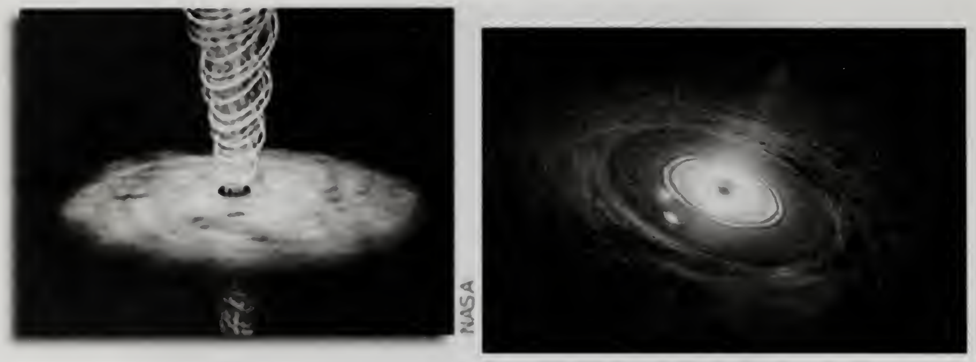


Figure 8. Two artists' conception of a black hole surrounded by an accretion disk and bipolar jets.

Observational Evidence for Black Holes

All this fancy theory means little unless there is observational evidence. Fortunately, despite its invisible interior, a black hole can be detected through its interaction with other matter.

There are several types of interactions. Five of them are: (1) A black hole exerts gravitational pull on surrounding matter, although this is indistinguishable at $r >> r_s$, from the pull of an object with the same mass; (2) Gas surrounding a black hole is pulled inward and heated so that it emits x-rays and gamma rays that might be observed; (3) A lump of matter falling into a black hole should emit a burst of gravitational waves; (4) Tidal forces will tear matter apart and eject a blob of relativistic matter (tube-of-toothpaste effect); (5) Frame dragging will twist the magnetic field lines that may surround a black hole and thus 'shake' the external plasma.

Figure 8 gives two artists' conception of a black hole surrounded by an accretion disk with two polar jets. Conservation of angular momentum means gas falling into the gravitational well created by a massive object will typically spiral in to form a Frisbee-like structure (accretion disk) around the object. **Accretion disks are where the action is.** In the case of black holes, the accretion disk is outside the event horizon. The gas in the inner regions (closer to the event horizon) becomes so hot that it will emit vast amounts of radiation (mainly x-rays), which may be detected by telescopes. In many cases, accretion discs are accompanied by relativistic jets emitted along the poles, which carry away much of the energy. The mechanism for the creation of these jets currently is not well understood, although frame dragging is part of the solution.

It is unlikely we can observe an accretion disk directly (they are too small), but the jets are easily seen (there are examples later in the paper).

The strongest evidence for black holes comes from binary star systems in which a visible star orbits a massive but unseen companion. Binary x-ray sources[xxiv] are excellent candidates for black holes because matter from the accretion disk streaming into the black hole is ionized and greatly accelerated, producing x-rays.

In 1972 an x-ray source (named Cygnus X-1) was discovered in the constellation Cygnus. The Cyg X-1 system has a blue supergiant star (HDE226868), about 25 times the mass of the sun, orbiting the x-ray source. So something non-luminous is there (neutron star or black hole). Figure 9 is an artist's conception of the Cyg X-1 system. The indirect evidence for the black hole Cyg X-1 is a good example of the search for black holes.

Doppler studies of the blue supergiant indicate a revolution period of 5.6 days about the dark object. Using that period plus spectral measurements of the visible companion's orbital speed leads to a calculated total system mass of about 35 solar masses.[xxv] The calculated mass of the dark object then is 8 to 10 solar masses; much too massive to be a neutron star which has an upper limit of about 3 solar masses – hence black hole. Figure 10 is an image of the system. The jet is clearly seen.

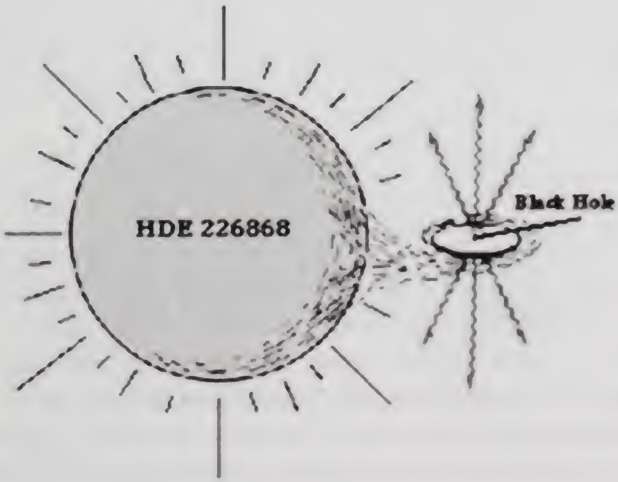


Figure 9. Artist's conception of Cygnus X-1 – matter is drawn from the supergiant star into an accretion disk around the black hole.

Further evidence for a black hole is the emission of x-rays from its location, an indication of temperatures in the millions of degrees. This x-ray source exhibits rapid variations, with time scales on the order of a millisecond. The light travel time is then a light-millisecond. This suggests a source not larger than a light-millisecond (300 km), so it is very compact. The only possibility that would place that much matter in such a small volume is a black hole.

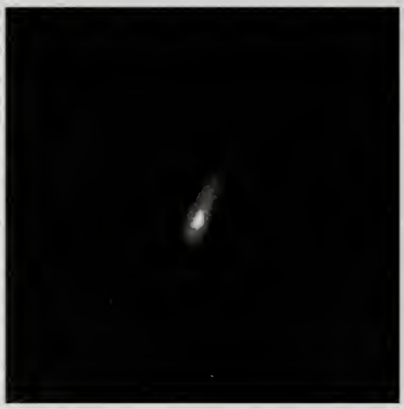


Figure 10. Jet in Cyg X-1, the jet is coming out from the center toward 1 o'clock. The accretion disk is much too small to see.

In November 2010 evidence of the youngest black hole (all of 30 years old) known to exist in our cosmic neighborhood was found. This object provides a unique opportunity to watch a black hole develop from near infancy. The object is a remnant of supernova 1979C, a supernova in the galaxy M100 approximately 50 million light years from Earth. The scientists think the progenitor star for the supernova was a star about 20 times more massive than the Sun.

Astronomers have identified numerous stellar black hole candidates, and have also found evidence of super massive black holes at the center of galaxies. In 1998, astronomers found compelling evidence that a super massive black hole is located near the Sagittarius A* region (a bright and very compact astronomical radio source discovered in 1974 at the center of our own Milky Way). Astronomers monitored the orbits of individual stars very near the black hole and used Kepler's laws to infer the enclosed mass. Recent results indicate that the super massive black hole is 4.31 ± 0.38 million solar masses. Ultimately, what is seen is not the black hole itself, but observations that are consistent only if there is a black hole present near Sgr A.* There is a nice time lapse movie of the stellar motions in the area: http://apod.nasa.gov/apod/ap001220.html.

Super massive black holes can produce amazing jets. Figure 11 shows three jets from the object 3C 75 (object number 75 in the Third Cambridge Catalogue of radio sources).

Figure 11. The right image is of 3C 75 – there are three clear jets. They originate at the bright spot in the center. The jets flare and bend as they encounter the intergalactic medium. The left image is an optical image of the galaxy NGC 1128 – the central bright dots in the right image.

The jets emanate from the vicinity of two super massive black holes (coming from the bright spot in the right image). These black holes are in the dumbbell galaxy NGC 1128, which has produced the giant radio source, 3C 75. The jets can reach incredible lengths – megaparsecs[xxvi] – streaming into intergalactic space.

The peculiar dumbbell structure of this galaxy is thought to be due to two large galaxies that are in the process of merging. Such mergers are common in the relatively congested environment of galaxy clusters. An alternative hypothesis is that the apparent structure is the result of a coincidence in time when the two galaxies are passing one another, like ships in the cosmic sea.

There is more. Black holes can come in pairs! Galaxies commonly collide and merge to form new, more massive galaxies. A merger between two galaxies should bring two super massive black holes to the new, more massive galaxy formed from the merger. The two black holes gradually spiral towards the center of this new galaxy, engaging in a gravitational tug-of-war with the surrounding stars. The result is a black hole dance.

Astronomers expect many such waltzing super massive black holes in the universe, but until recently only a handful had been found. In January of 2010, astronomers announced the discovery of 33 pairs of waltzing black holes in galaxies. This result shows that super massive black hole pairs are more common than previously known from observations. Also, the black hole pairs can be used to estimate how often galaxies merge with each other.

The largest known black hole inhabits the core of M87, a giant elliptical galaxy in the constellation Virgo. The M87 black hole appears to be about $(6.4 \pm 0.5) \times 10^9$ solar masses, with an event horizon diameter of about 18 billion km – almost twice the diameter of the orbit of Pluto. Figure 12 contains a series of photos of M87 with its jet. Surrounding the black hole is a rotating disk of ionized gas that is oriented roughly perpendicular to the jet. This gas is moving at velocities of up to roughly 1,000 km/s. Gas is accreting onto the black hole at an estimated rate equal to the mass of the Sun every ten years.

Conclusion

Black holes retain their fascination despite the decades of solid research. They are both simple and complex: simple because it takes only three parameters to describe them; complex because it takes GTR to handle the dynamics. They come singly, in binary systems, and in pairs, but never 'naked'. They come both small and large in mass. They are impossible to see, but their effects on their environment can be distinctive, although they are not cosmic vacuum cleaners. We think they are found in the centers of most galaxies. There are dozens of possible detections of stellar mass black holes.

Gravity trumps all the other forces of nature in these objects. It compresses the mass of a dozen Suns, or a million, or a billion into a pinpoint of infinite density. Space and time are squeezed out of existence, and the structure of the universe turns into a "quantum foam" that's ruled by laws that scientists do not yet fully comprehend. We have a lot more to learn.

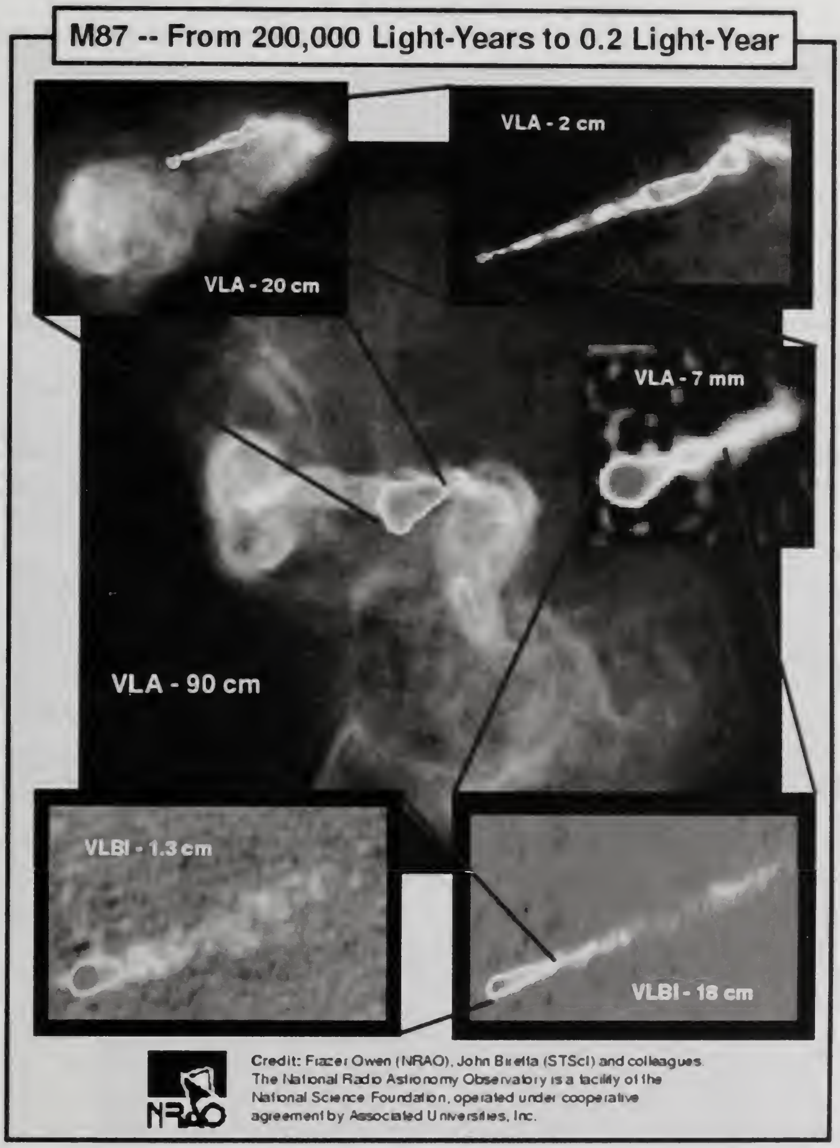


Figure 12. A series of multi-wavelength photos of M87 and its jets. Lobes of matter from the jet extend out to a distance of 250,000 light-years. Start in the center, then move to the upper left and follow clockwise the expansions of each image.

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[i] The term 'black hole' was first publicly used in 1967 by physicist John Wheeler during a lecture. He always insisted that it was suggested to him by somebody else.

[ii] John Michell (1724 – 1793) was an English natural philosopher and geologist whose work spanned a wide range of subjects from astronomy to geology, optics, and gravitation.

[iii] Henry Cavendish FRS (1731 – 1810) was a British scientist noted for his discovery of hydrogen which he called inflammable air.

[iv] Michell, J. "On the Means of Discovering the Distance, Magnitude, &c. of the Fixed Stars, in Consequence of the Diminution of the Velocity of Their Light, in Case Such a Diminution Should be Found to Take Place in any of Them, and Such Other Data Should be Procured from Observations, as Would be Farther Necessary for That Purpose." *Phil. Trans. R. Soc. (London)* **74**: 35–57 (1784).

[v] Pierre-Simon, marquis de Laplace (23 March 1749 – 5 March 1827) was an astronomer/mathematician.

[vi] It represents the curvature in a Riemannian manifold. A tensor is a geometrical higher-order vector. Think of a matrix, although all matrices are not tensors.

[vii] Einstein called Λ his greatest blunder. Today scientists use it to explain 'dark energy'. It was originally introduced by Einstein to allow for a static universe (*i.e.*, one that is not expanding or contracting). This effort was unsuccessful for two reasons: the static universe described by this theory was unstable, and observations of distant galaxies by Hubble a decade later confirmed that our universe is, in fact, not static but expanding.

[viii] This allows one to measure intervals and to define distance in the curved space.

[ix] On the outbreak of war in August 1914 Schwarzschild volunteered for military service. While at the Russian front he wrote two papers on relativity theory providing the first exact solution to the field equations.

[x] A few months after Schwarzschild's work, mathematician Johannes Droste independently gave the same solution for the point mass.

[xi] Singularities are difficult to describe. They are absolute termination points – cessation of existence.

[xii] Actually Schwarzschild solved the equations with no mass and, then, in the weak field approximation, used the mass to bring it into coincidence with the Newtonian limit.

[xiii] Stationary means the black hole might rotate but not translate. A non-stationary black hole might be one that is orbiting another object.

[xiv] There are other metrics that are beyond the scope of this paper.

[xv] Bardeen J.M., Carter, B., Hawking, S., *Commun. Math. Phys.* **31**, 161-170 (1973)

[xvi] This means the infinity disappears in some coordinate systems.

[xvii] D. Finkelstein, Phys. Rev. **110**, 965–967 (1958).

[xviii] Which means we do not really know what happens.

[xix] It can orbit at this distance (and not fall in) if it moves quickly enough.

[xx] The $\sqrt{-1}$ is not allowed.

[xxi] *Science News*, **178**, p 28.

[xxii] See JWAS, Winter 2010 issue for a description of this experiment.

[xxiii] White holes cannot exist, since they violate the second law of thermodynamics.

[xxiv] Binary x-ray sources have a visible star and an invisible source of x-rays.

[xxv] Because angular momentum is conserved, observations of binary systems can give the total mass of the system.

[xxvi] 1 parsec is $3.08568025 \times 10^{13}$ km.

The Dark Side of Astronomy

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With all that starlight around how can there be dark stuff? Astronomers now routinely use dark matter and dark energy to match observations. I discuss both dark matter and dark energy, describing their properties and implications. Despite all we do know, there is far more that we do not know.

Introduction

For millennia astronomy has used information gleaned from the electromagnetic spectrum – first with optical light and then with other wavelengths. The universe is awash in light. One might even ask why the night sky is dark with all that light around. This is known as Olbers' paradox: a dark sky conflicts with an infinite and unchanging universe. The light from an infinite number of stars will fill the sky, and yet the night sky is dark. The Big Bang Model solves this paradox. According to the model the universe has a finite age (so there are not an infinite number of stars), and the universe is expanding. The original light from the Big Bang event is now in the microwave regime – the cosmic microwave background – where our eyes do not see it. It takes a very sensitive microwave detector to 'see' the cosmic microwave background. So we have our beautiful dark night sky.

Figure 1. The Coma cluster of galaxies

In 1933 the Swiss astrophysicist Fritz Zwicky observed the Coma cluster of galaxies. This cluster contains over 1000 galaxies and is found in the constellation of Coma Berenices. Figure 1 is an optical image of the Coma cluster. All of the asymmetrical objects in the figure are galaxies.

Zwicky asked the question: what is the total mass of the cluster? At this time in astronomical history, there was no robust way to estimate the mass of an individual galaxy. If there were, one could simply add up the individual masses. He estimated the cluster's total mass in two ways:

(1) Based on the motions of galaxies near its edge under the assumption that the galaxies were not escaping and were bound to the cluster. This is a good assumption. It says the cluster is a bound system and is not flying apart; and

(2) Based on the number of galaxies and total brightness of the cluster. In other words mass follows light (this means the mass to light ratio is unity when both are measured in solar units $\frac{\mathcal{M}}{\mathcal{L}} = 1$ where $\mathcal{M}$ is the mass and $\mathcal{L}$ is the luminosity). At the time this was also a good assumption. He could measure the brightness and therefore infer the mass.

He found that there was about 400 times more estimated mass using method (1) than was visually observable by method (2). This is far outside any error of measurement. This means that the gravity of the visible galaxies in the cluster (via method 2) was far too small to constrain (bind to the cluster) the moving galaxies, so something extra was required. Based on these conclusions, Zwicky inferred that there must be some non-visible form of matter that would provide enough of the mass and gravity to hold the cluster together. This unexpected result became known as the "missing mass problem."

Nothing changed for 40 years after Zwicky's initial observations. The missing mass remained missing. No observations indicated that the mass to light ratio was anything other than unity. With $\frac{\mathcal{M}}{\mathcal{L}} = 1$ the implication is that the circular velocity of the stars revolving about a galaxy center would drop with distance from the galaxy center – similar to a Keplerian drop-off.[i] In other words, as one moves from galaxy center to edge the light decreases and so, therefore, does the mass. Astronomers did question the issue, but there was no resolution. I remember when I was a mere research assistant at Lick Observatory in 1965. I knew nothing of this issue, so when a staff astronomer asked me if the mass to light ratio

could be other than unity I said, showing my ignorance, of course, why not. He smiled a gentle, forgiving smile.

Initial Observations of Dark Matter

Then, in the late 1960s and early 1970s, Vera Rubin, a young astronomer at the Carnegie Institution of Washington presented findings based on measurements of the velocity curve[ii] of spiral galaxies to a greater degree of accuracy than had ever before been achieved.

Spiral galaxies look rather like cosmological fried eggs. They are quite flat when seen edge-on, and display a wide variety of circular shapes when seen face-on. See Figure 2 for two examples.

Together with fellow staff-member Kent Ford, Rubin announced at a 1975 meeting of the American Astronomical Society the discovery that most stars in spiral galaxies orbit at roughly the same speed (approximately 220 km/s) regardless of distance from the center. This implies that their mass densities are uniform well beyond the location with most of the stars (the galactic bulge; *i.e.*, the yolk in the fried egg). This means that even though the light falls off as one moves away from the center, the mass does not. These results suggest that either Newtonian gravity does not apply universally (an unacceptable conclusion), or that, conservatively, upwards of 50% of the mass of galaxies are contained in a relatively dark *galactic halo*.

Figure 2. The left image is a spiral galaxy seen almost face-on. It has intricate structure. The right image is another spiral galaxy seen edge-on. It looks flat.

A galactic halo is a spherical distribution of matter surrounding a spiral galaxy. The spiral disk 'floats' in the middle of the spherical ball of dark matter. Dark matter responds to gravity but nothing else. It cannot be 'seen' in any part of the electromagnetic spectrum.

Met with skepticism, Rubin insisted that the observations were correct. Eventually other astronomers began to corroborate her work, and it soon became well-established that most galaxies were in fact dominated by dark matter. Zwicky was vindicated.

Figure 3 illustrates the issue. A rotation curve is the locus of points for the circular speed as a function of distance from the galaxy center. 'A' (the dotted line) represents the expected Keplerian drop-off in orbital speed with distance – the farther from the center the slower the star travels. 'B' (the solid line) represents Rubin's observational results.

Rubin's pioneering work has stood the test of time. Measurements of velocity curves in spiral galaxies were soon followed by velocity dispersions of elliptical galaxies.

Elliptical galaxies are rather like cosmological hard boiled eggs. They look the same regardless of the direction of view. See Figure 4. Measurements of the velocity dispersions in ellipticals also indicate a high dark matter content.

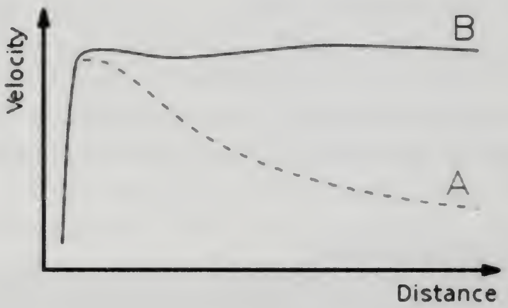

Figure 3. Rotation curve of a typical spiral galaxy: predicted (**A**) and observed (**B**). Dark matter can explain the velocity curve having a 'flat' appearance out to a large radius. The velocity is plotted on the y axis, and the distance from the galaxy center on the x axis.

Figure 4. An image of an elliptical galaxy.

More Observations of Dark Matter

Rubin estimated a dark matter component that was 50% of the total amount of gravitating matter. Subsequent measurements of the diffuse interstellar gas found at the outer edge of galaxies indicate that the galaxies are gravitationally bound up to ten times their visible radii. This has the effect of pushing up the dark matter component from the 50% measured by Rubin to the now accepted value of nearly 95%.

Measurements of dark matter are now routine. For example astronomers no longer assume that mass follows light – that the mass to light ratio is unity. Galaxy mass profiles are thought to look very different from their light profiles. The typical model for dark matter in galaxies is a smooth, spherical distribution in halos that surround the disk.

The Milky Way (our own galaxy) is part of the Local Group of galaxies. These are galaxies that form a close grouping with the Milky Way (including the Andromeda galaxy). Recently (2010) astronomers found that a member of the Local Group, the galaxy Segue 1, has a combined visual mass of about 1000 stars (it is a small galaxy) yet the whole mass is more than 500 times larger. Segue 1 may be made of mostly dark matter.[iii]

In 2005, astronomers from Cardiff University claimed to discover a galaxy made almost entirely of dark matter, 50 million light years away in the Virgo Cluster. This galaxy, named VIRGOHI21, does not appear to contain any visible stars: it was seen with radio frequency observations of hydrogen. Based on rotation profiles, the scientists estimate that this object contains approximately 1000 times more dark matter than hydrogen and has a total mass of about 1/10th that of our own Milky Way. For comparison, the Milky Way is believed to have roughly 10 times as much dark matter (in its halo) as ordinary matter. Skeptics of this interpretation argue that VIRGOHI21 is simply a tidal tail of the nearby galaxy NGC 4254. The nature of this galaxy remains a contentious issue.

Low surface brightness (LSB) dwarf galaxies are important sources for studying dark matter, because they have an uncommonly low ratio of visible matter to dark matter (hence the name), and have few bright stars at the center which would otherwise impair observations of the rotation curve of outlying stars. LSBs are probably dark matter-dominated, with the observed stellar populations making only a small contribution to rotation curves. This class of galaxy is extremely important because it allows one to avoid the difficulties associated with the de-projection (the

tilt of the disk to the line-of-sight) and disentanglement of the dark and visible contributions to the rotation curves.

Dark matter has the ability to deflect light.[iv] Gravitational lensing observations of galaxy clusters allow direct estimates of the true gravitational mass based on its effect on light from background galaxies. In clusters such as Abell 1689 (Figure 5), lensing observations confirm the presence of considerably more mass than is indicated by the clusters' light alone. The short, thin arcs of light in the image are due to lensing.

Figure 5. Cluster Abell 1689

According to observations of structures larger than galaxies, as well as Big Bang cosmology, dark matter accounts for 23% of the mass-energy density of the observable universe. In comparison, ordinary matter accounts for only 4.6% of the mass-energy density of the observable universe, with the remainder attributable to dark energy. From these figures, dark matter constitutes 83% of the matter in the universe, while ordinary matter makes up only 17%. Figure 6 illustrate the various percentages for today and for 13.7 billion years ago.

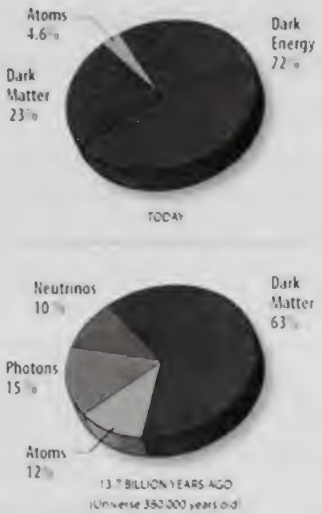

Figure 6. The top pie chart gives the percentages for today. The bottom pie chart gives the percentages for 13.7 billion years ago according to the Big Bang Theory.

Counter Examples for Dark Matter?

There are a few galaxies that have velocity profiles that indicate an absence of dark matter, such as the elliptical galaxy NGC 3379. However in 2006, using observations of globular clusters in NGC 3379, astronomers found evidence for normal quantities of dark matter in the galaxy's dark halo. This is contrary to the previous observations that indicated a paucity of dark matter in the galaxy.

Globular clusters (10^5 stars) are sprinkled in the halos of spiral galaxies.[v] They show little evidence that they contain dark matter.

It is important to note here that it is possible to form a spiral disk of stars and gas that follows a flat rotation curve without bringing in dark matter. The Mestel gravitational potential can accomplish this. The astronomer Mestel was an expert in galaxy dynamics.[vi] A Mestel disk (with a flat rotation curve) forms when a uniformly rotating spherical cloud with slightly decreasing density (center to edge) collapses while conserving angular momentum. Such a disk is an observationally close approximation to a thin disk of stars and gas. However, these disks are difficult to maintain. They tend to become gravitationally unstable unless there is some dark matter in a spherical halo surrounding the disk. A 3D spherical gravitational field will stabilize the disk against fragmentation.

These few counter examples are not very robust. Dark matter seems firmly established through observations.

What Is Dark Matter?

All of these observations of dark gravitating matter beg the question, just what is it?

First, the chief property of dark matter is that it is "dark," *i.e.* it emits no light – not visible, not x-ray, not infrared. So it is not large clouds of hydrogen gas, since we can usually detect such clouds in the infrared or radio. It is not in the form of stars and planets that we can see in the optical.

Second, dark matter must interact with visible matter gravitationally. So the dark matter must be massive enough to cause the gravitational effects that we see in galaxies and clusters of galaxies.

Third, dark matter is not antimatter because we do not see the unique gamma rays that are produced when antimatter and matter annihilate.

Fourth, dark matter particles must be electrically neutral; otherwise they would scatter light and thus not be dark.

Finally, we can rule out large galaxy-sized black holes on the basis of how many gravitational lenses we see. High concentrations of matter bend light passing near them from objects further away, but we do not see enough lensing events to suggest that such objects make up the required 25% of dark matter contribution.

That is it. In other words, we do not know much.

However, there are a few viable dark matter possibilities. The two main categories of objects that scientists consider as possibilities for dark matter include MACHOs (yes, really!) and WIMPs (again, really!). These are acronyms which help astronomers to remember what they represent.

MACHOs (<u>MA</u>ssive <u>C</u>ompact <u>H</u>alo <u>O</u>bjects): MACHOs are objects ranging in size from small stars to super massive black holes. MACHOs are made of ordinary matter (like protons, neutrons and electrons) and are found in the halos of galaxies.

Astronomers detect MACHOs by using their gravitational effects on the light from distant objects. The gravitational attraction of a massive object can bend the path of a light ray, much like a lens does. So when a massive dark MACHO passes in front of a distant object (*e.g.* a star or another galaxy), the light from the distant object is "focused" and the distant object appears brighter for a short time. Astronomers search for

MACHOs in the halo of our Galaxy by monitoring the brightness of stars near the center of our Galaxy and in the Large Magellanic Cloud (LMC).[vii]

The MACHO Project, one of the groups using this gravitational lens technique, observed about 15 lensing events toward the LMC over a span of six years of observations. They set a limit of 20% as the contribution to the dark matter in our Galaxy due to objects with mass less than 0.5 that of the Sun. So while they have been observed, astronomers have found no evidence of a large enough population of these objects that would account for all the dark matter in our Galaxy.

What about neutron stars and black holes as MACHOs? Neutron stars and black holes are the final results of a supernova of a massive star. Because a supernova usually leaves behind a remnant cloud of visible gas, neutron stars and black holes must travel far from the remnant to "hide."

On the positive side neutron stars are very massive, and if they are isolated, they can be dark. On the negative side, because they result from supernovae, they are not necessarily common objects. There is no evidence that they occur in sufficient numbers in the halos of galaxies.

Black holes are not likely sources of dark matter because they have such a dramatic effect on their surroundings –they typically produce high energy jets that are easy to observe.

The most common view is that dark matter is not ordinary matter (electrons, protons, neutrons) at all; instead it is made up of other, more exotic particles like axions or WIMPs (Weakly Interacting Massive Particles).

WIMPs are subatomic particles which are not made up of ordinary matter. They are weakly interacting because they can pass through ordinary matter without any effects. They are massive in the sense of having mass (whether they are light or heavy depends on the particle). The prime candidates include neutrinos, axions, and neutralinos.

Neutrinos were first "invented" by physicists in the early 20th century to make particle physics interactions work properly. They were later discovered, and physicists and astronomers had a good idea how many neutrinos there are in the Universe. But they were thought to be without mass. In 1998 one type of neutrino was discovered to have a mass, albeit very small. This mass is too small for the neutrino to contribute significantly to the dark matter despite the large number of them present in the Universe.

Axions are particles which have been proposed to explain the absence of an electrical dipole moment for the neutron. They thus serve a purpose for both particle physics and for astronomy. Although axions may not have much mass, they would have been produced abundantly in the Big Bang. Current searches for axions include laboratory experiments and searches in the halo of our Galaxy and in the Sun.

Neutralinos are members of another set of particles that have been proposed as part of a physics theory known as supersymmetry. This theory is one that attempts to unify all the known forces in physics. Neutralinos are proposed as massive particles (they may be 30× to 5000× the mass of the proton), but they are also the lightest of the electrically neutral supersymmetric particles. Astronomers and physicists are developing ways of detecting the neutralino either underground or searching the universe for signs of their interactions. A lightest neutralino of roughly 10–10000 GeV is the leading WIMP dark matter candidate.

So far there have been *no* detections of axions or neutralinos.

There are other factors that help scientists determine the mix between MACHOs and WIMPs as components of the dark matter. Recent results by the WMAP satellite[viii] show that our universe is made up of only 4% ordinary matter. This seems to exclude a large component of MACHOs. About 23% of our universe is dark matter. This favors the dark matter being made up mostly of some type of WIMP. However, the evolution of structure in the universe indicates that the dark matter must not be fast moving, since fast moving particles prevent the clumping of matter in the universe. We want clumping because galaxies and planetary systems form from such clumps. So while neutrinos may make up part of the dark matter, they are not a major component because they move too fast. Particles such as the axion and neutralino appear to have the appropriate properties to be dark matter. However, they have yet to be detected.

The conclusion is that we simply do not know what makes dark matter; however, the evidence is strong that there is *something* dark that responds to gravity.

Ordinary matter and dark matter make up only about 28% of the Universe. That leaves us with the majority player in the universe – dark energy.

Dark Energy

In the early 1990's, one thing was fairly certain about the expansion of the Universe. It was expanding. It might have enough energy density to stop expanding and re-collapse, it might have so little energy density that it would never stop expanding, but gravity was certain to slow the expansion as time went on. Granted, the slowing had not been observed, but, theoretically, the Universe had to slow. The Universe is full of gravitating matter and the attractive force of gravity pulls all matter together.

Then in the late 1990's two teams[ix] published observations of Type Ia supernovae (SN). Since then, these observations have been corroborated by several independent sources. The latest studies (in 2011) have reinforced the results, shrinking the error bars by about 30 percent.

A Type Ia SN is a sub-category of cataclysmic variable stars that results from the violent explosion of a white dwarf star. A white dwarf is the remnant of a star that has completed its normal life cycle and has ceased nuclear fusion. Type Ia SN have a characteristic light curve, the graph of luminosity as a function of time after the explosion. See Figure 7.

The similarity in the absolute luminosity profiles of nearly all known Type Ia SN has led to their use as a secondary standard candle in the distance ladder used in extragalactic astronomy. The cause of this uniformity in the luminosity curve is still an open question.

That means if a Type Ia SN is observed in a distant galaxy then we know the distance to that galaxy. We observe the apparent luminosity and since all Type Ia's have the same absolute luminosity we can use the distance-luminosity relation[x] to get the distance.

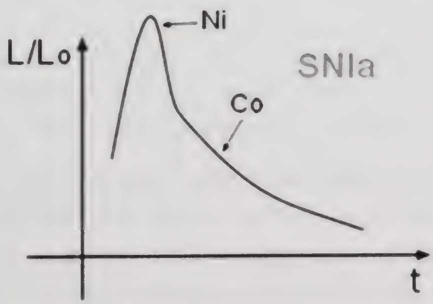

Figure 7. An illustration of the light curve of a supernova Type Ia. Luminosity is plotted versus time since the explosion. These are good for standard candles because the maximum luminosity is always the same for this type of supernova.

These observations showed that, a long time ago, the Universe was actually expanding more slowly than it is today. So the expansion of the Universe has not been slowing due to gravity, as everyone thought; it has been accelerating. The Big Bang impelled galaxies apart in an expanding Universe. But in defiance of cosmic gravity it appears that galaxies are picking up speed instead of slowing down. This is shocking. No one expected this; no one knew how to explain it; it was an enormous surprise. But there it was in the data.

The extra expansion of the Universe in recent times is revealed by the excessive faintness of distant Type Ia SN, whose brightness calibrates their distances. In other words the supernovae were too faint for their type – they are further away than they ought to be due to their brightness. For them to be as faint as they are, the Universe had to speed up to get them as distant as they are observed to be. See Figure 8.

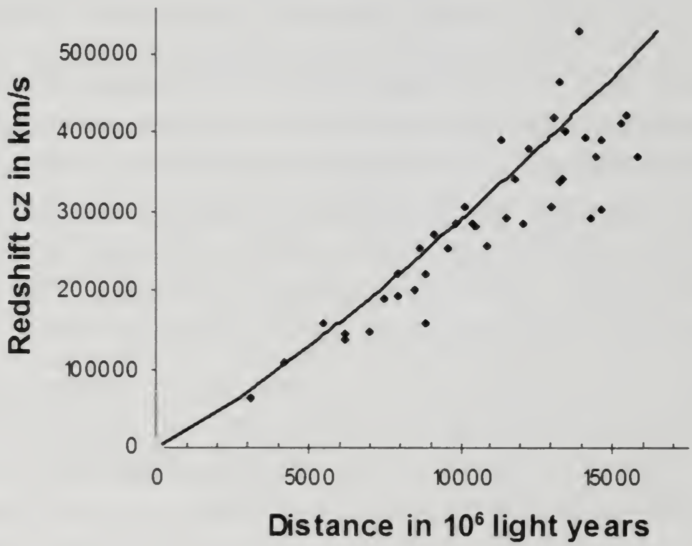

Figure 8. The small dots are measurements of a supernova plotted as distance versus redshift. The solid line marks where the mean ought to fall if the universe were uniformly expanding. Note that the distant supernovae fall beneath the line; therefore, the observations show that the supernovae are fainter than expected.

Dark energy is hardly science fiction. What is true for a ball tossed in the air only to return to Earth is not true for the Universe. Although cosmologists adopted a cute name, dark energy, for whatever is driving this apparently anti-gravitational behavior on the part of the Universe, nobody claims to understand why it is happening, or its implications for the future of the universe and of the life within it, despite thousands of learned papers and scores of conferences.

Figure 9 shows a diagram of how the Universe might have evolved within the concept of dark energy.

The consequences of dark energy for fundamental physics will not be clear until its origin is discovered, but the effects on the universe are dramatic. Dark energy effectively contributes 70-75% of the current energy density of the Universe, governing the expansion of space, causing it to accelerate over the last ~7 billion years, and will determine the fate of the Universe. Such a phenomenon is not predicted within the experimental experience of gravity as an attractive force.

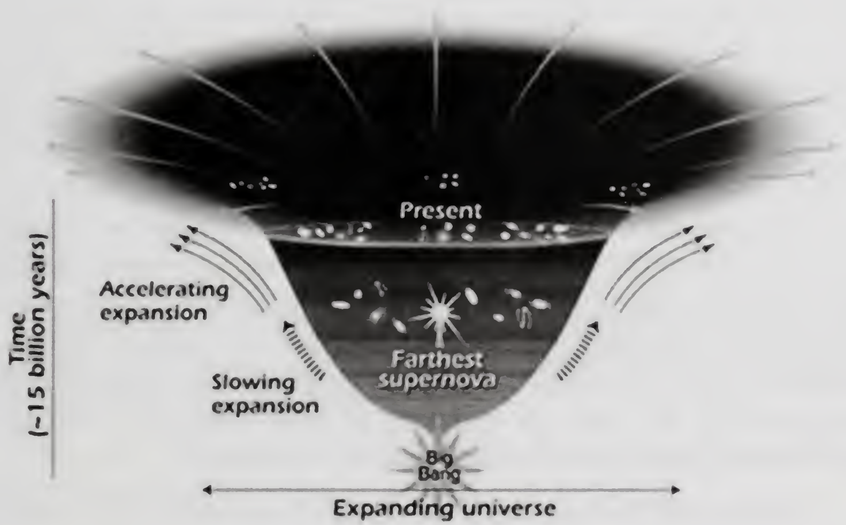

Figure 9. This diagram shows changes in the rate of expansion since the Universe's birth 13.7 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the Universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark energy that is pulling galaxies apart. Credit: NASA/STSci

Gravitation as an attractive force acts to slow down the cosmic expansion, so dark energy acts in this sense as antigravity or cosmic repulsion. This can however occur within general relativity for substances with strongly negative pressure. Recall the main set of equations for the theory of general relativity:

$$G_\mu^\nu + \Lambda g_\mu^\nu = \frac{8\pi G}{c^4} T_\mu^\nu .$$

The left side essentially says that space is driven by geometry. The right side says that energy and mass follow that geometry. The second term on the left hand side was inserted by Einstein to obtain the stationary

Universe he believed it to be: 'Λ' is the *cosmological constant*. He abandoned the term after Edwin Hubble's observations showed that the Universe was expanding.

It is now thought that adding the cosmological constant term to Einstein's equations does not lead to a static Universe at equilibrium because the equilibrium is unstable; if the Universe expands slightly, then the expansion releases vacuum energy, which causes yet more expansion. Likewise, a Universe which contracts slightly will continue contracting.

The nature of this dark energy is a matter of speculation. It is known to be very homogeneous, not very dense, and is not known to interact through any of the fundamental forces other than gravity. Since it is not very dense—roughly 10^{-29} grams per cubic centimeter—it is hard to imagine experiments to detect it in the laboratory. Dark energy can only have such a profound impact on the Universe, making up 74% of universal density, because it uniformly fills otherwise empty space.

Various types of dark energy have been proposed, including a cosmic field associated with inflation; a different, low-energy field dubbed "quintessence" (named after the ancients Greeks' fifth element); and the cosmological constant, or vacuum energy of empty space. Unlike Einstein's Λ, the cosmological constant in its present incarnation does not balance gravity in order to maintain a static Universe; instead, it has negative pressure that causes expansion to accelerate.

Empirically, the onslaught of cosmological data in the past decades (all those observations of Type Ia SN) strongly suggests that our Universe has a positive cosmological constant. The explanation of this small but positive value is an outstanding theoretical challenge. The challenge comes from explaining dark energy as a property of space. Einstein was the first person to realize that empty space is not empty. It has the property that it is possible for more space to come into existence.

The version of Einstein's gravity theory that contains a cosmological constant makes a prediction: empty space can possess its own energy. Because this energy is a property of space itself, it would not be diluted as space expands. As more space comes into existence, more of this energy-of-space would appear. As a result, this form of energy would cause the universe to expand faster and faster. Unfortunately, no one understands why the cosmological constant should even be there, much less why it would have exactly the right value to cause the observed acceleration of the Universe.

Another explanation for how space acquires energy comes from the quantum theory of matter. In this theory, empty space is actually full of temporary (virtual) particles that continually form and then disappear (a kind of quantum foaming). But when physicists tried to calculate how much energy this would give empty space, the answer came out wrong – wrong by a lot. The number came out 10^{120} times too big. It's hard to get an answer that bad. So the mystery continues.

A last possibility is that Einstein's theory of gravity is not correct. That option would not only affect the expansion of the Universe, but it would also affect the way that normal matter in galaxies and clusters of galaxies behaved. This fact would provide a way to decide if the solution to the dark energy problem is a new gravity theory or not: we could observe how galaxies come together in clusters. But if it does turn out that a new theory of gravity is needed, what kind of theory would it be? How could it correctly describe the motion of the bodies in the Solar System, as Einstein's theory is known to do, and still give us the different prediction for the universe that we need? There are candidate theories, but none are compelling.

The thing that is needed to decide between dark energy possibilities – a property of space, a new dynamic fluid, or a new theory of gravity – is more and better data.

Theorists still don't know what the correct explanation is, but at least they have given the solution a name – dark energy.

Dark Energy Opponents

Not all experts are comfortable with the idea that a strange force is mysteriously tugging the universe apart.

One alternative is the idea that our cosmic neighborhood – the solar system and the whole Milky Way – happens to sit at the center of a relatively empty bubble of space eight billion light-years across (a void). If this were the case, we would measure the same accelerated expansion rate we do, except it would be an illusion created by our special position in the void.

But the latest precision measurements of the universe's acceleration seem to rule out that idea, which predicts a somewhat different value for the expansion rate. However, the latest results do not disqualify all versions of the void model. In some more complicated

scenarios in which the Big Bang did not happen at the same time at all points in space, this hypothesis could still be valid.

However, ultimately many scientists are dubious of all the void models because they put us in a special place in the universe. Copernicus shot that idea down.

Some Current Work

Arthur Chernin[xi] and his colleagues are working on applying dark energy on small cosmic scales. In the standard Cold Dark Matter model with dark energy (ΛCDM), all celestial bodies are embedded in a perfectly uniform dark energy background and experience a repulsive antigravity action. In the cold dark matter theory, structure grows hierarchically, with small objects collapsing first and merging in a continuous hierarchy to form more and more massive objects. In the hot dark matter paradigm, popular in the early eighties, structure does not form hierarchically (*bottom-up*), but rather forms by fragmentation (*top-down*), with the largest superclusters forming first in flat pancake-like sheets and subsequently fragmenting into smaller pieces like our Galaxy the Milky Way. The predictions of hot dark matter strongly disagree with observations of large-scale structure, whereas the cold dark matter paradigm is in general agreement with the observations. So the cold dark matter approach is the one favored currently.

Chernin's team asks the question, can dark energy have strong dynamical effects on small cosmic scales as well as large scales? The distant supernovae give us the global effect of dark energy; is there an effect on a scale as small as the Local Group? They find that the antigravity produced by dark energy is stronger than the gravity of the Local Group at distances larger than ~15 Mpc from the group center. In other words, the answer to their question is yes. The effects of dark energy can be seen on many different scales.

Conclusion

More is unknown than is known. We know how much dark energy there is because we know how it affects the Universe's expansion. Other than that, it is a complete mystery. But it is an important mystery. It turns out that roughly 70% of the Universe is dark energy. Dark matter makes up about 25%. The rest – everything on Earth, everything ever observed with all of our instruments, all normal matter – adds up to less than 5% of

the Universe. Maybe it should not be called normal matter at all, since it is such a small fraction of the Universe.

What do we know? We know that the light we can detect makes for a Universe filled with beautiful things, and for us here on Earth, that light makes an awesome night sky.

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[i] A Keplerian drop-off is what the planets do in our Solar System. The farther from the Sun, the slower the planet travels.

[ii] A velocity curve is a plot of circular velocity (y axis) versus distance from the center (x axis).

[iii] *Science News* August 28, 2010.

[iv] Just as non-dark matter does.

[v] A globular cluster is small spheroid of densely packed stars ~10^6 stars. Globular clusters orbit around the disk of spiral galaxies. There are, for example, about 100 globular clusters surrounding the Milky Way.

[vi] L. Mestel, *ApJ*, **126**, 553, 1963.

[vii] The LMC is another member of the Local Group of galaxies.

[viii] A satellite observing the cosmic microwave background.

[ix] One at U. Berkeley and one at the Space Telescope Science Institute.

[x] $M - m = -5(\log_{10} d - 1)$ where M is the absolute magnitude, m is the apparent magnitude, and d is the distance.

[xi] A. Chernin *et al. Astronomy & Astrophysics*, **520**, 104, 2010.

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Cosmic Distance Ladder

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Abstract

Astronomers use a wide variety of methods to determine the distance to celestial objects. The ultimate goal is to obtain the Hubble constant and establish the Hubble law. With this law one can measure the most distant object and determine the parameters that control our universe.

Introduction

THERE IS NO METER STICK long enough to reach the stars; therefore, astronomers use a succession of methods to determine the distances to celestial objects. This succession is known as the *cosmic distance ladder*. It has taken millennia to figure how to measure such extreme distances, extreme, that is, compared to distances here on Earth.

Measurements of the size of the Earth go back in time to at least the ancient Greeks. Eratosthenes (3^{rd} century BCE) came surprisingly close to determining the radius of the Earth (he was perhaps one sixth too high). Eratosthenes also invented the concepts of latitude and longitude. The great Indian mathematician Aryabhata (CE 476 – 550) was a pioneer of mathematical astronomy. He came within one percent of the current value for the circumference of the Earth. John O'Connor and Edmund Robertson[i] wrote of the medieval Persian Abu Rayhan al Biruni (CE 973 – 1048) that:

> Important contributions to geodesy and geography were also made by Biruni. He introduced techniques to measure the Earth and distances on it using triangulation. He found the radius of the Earth to be 6339.6 km, a value not obtained in the West until the 16^{th} century.

Triangulation is important in determining distances. Triangulation is the process of determining the location of a point by measuring angles to it from known points at either end of a fixed baseline, rather than measuring distances to the point directly. The point can then be fixed as the third point of a triangle with one known side and two known angles (the old angle-side-angle trick from geometry). This is a useful tool on Earth, especially for surveying.

If the triangle is *very* large (as it is in astronomy) then one can use the small angle approximation. Figure 1 shows the relationships for a large triangle. In this case, the distance *s* is very nearly equal to the distance *O*. The smaller the angle θ the closer they are to each other. The small angle approximation gives:

$$\sin\theta \approx \theta$$

$$\cos\theta \approx 1 - \frac{\theta^2}{2}.$$

$$\tan\theta \approx \theta$$

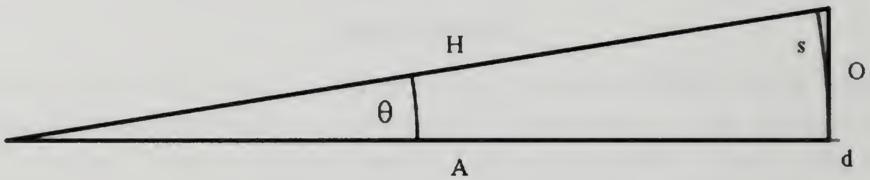

Figure 1. A large triangle where A is the distance from the origin to the point d.

In astronomy, the angle subtended by the image of a distant object is often only a few arcseconds, so it is well suited to the small angle approximation. The linear size (s) is related to the angular size (θ) and the distance from the observer (A) by the simple formula:

$$s = \theta \frac{A}{206265}$$

when θ is measured in arcseconds. The number 206,265 is approximately equal to the number of arcseconds in a circle (1,296,000) divided by 2π. The exact formula is:

$$s = 2A\tan\left(\frac{\theta\pi}{1296000}\right).$$

The above approximation follows when tan(θ) is replaced by θ.

The Astronomical Unit

Measurement starts locally with the Earth. Once people had a handle on Earth sized distances, and they had a tool kit of standard measuring devices (*e.g.*, the kilometer, the second, the gram), then they could consider measuring the sky. To begin with, astronomers needed a

precise determination of the distance between the Earth and the Sun, which is called the Astronomical Unit (AU).

Historically, the transits of Venus across the Sun were used for this. By measuring how long it took Venus to transit across the Sun, one could derive the value for the AU. Astronomers would observe the Venus transit in two different locations on Earth. Using the times of the transits they could calculate the solar parallax (which cannot be measured directly). By combining that with the relative distances of the Earth and Venus from the Sun they could calculate the AU. Parallax occurs when the eye sees an object appear to shift compared to distant objects.

Another method involved work by the astronomer Simon Newcomb in 1895. He also used data from the transits of Venus. He then collaborated with A. A. Michelson to measure the speed of light with Earth-based equipment; when combined with the constant of aberration (which is related to the light-time per unit distance) this gave the first direct measurement of the Earth–Sun distance in kilometers.

Astronomers now use radar and telemetry instead of transits. Precise measurements of the relative positions of the inner planets can be made by radar and by telemetry from space probes. As with all radar measurements, these rely on measuring the time it takes for light to reflect from an object. The measured positions are then compared with those calculated by the laws of celestial mechanics: the comparison gives the speed of light in AUs, which is 173.144 632 6847(69) AU/day. Because the speed of light in meters per second (c_{SI}) is fixed in the International System of Units, this measurement of the speed of light in AU/day (c_{AU}) also determines the value of the astronomical unit in meters:

$$AU = 86400\frac{c_{SI}}{c_{AU}}.$$

In 1976 the International Astronomical Union revised the definition of the AU for greater precision, defining it as that length for which the Gaussian gravitational constant takes the value 0.017 202 098 95 when the units of measurement are the astronomical units of length (AU), mass (solar mass) and time (day). The Gaussian gravitational constant is equal to the square root of the Newtonian gravitational constant G; it is also roughly equal to the mean angular velocity of the Earth in orbit around the Sun. The best current (2009) estimate of the International Astronomical Union (IAU) for the value of the AU in meters is 1 AU = 149 597 870 700(3) m.

The uncertainties of the various methods are given in Table I. The AU is given in Gigameters.

Table I – Uncertainty in measurement of the AU.

Date	Method	AU/Gm	Uncertainty
1895	aberration	149.25	0.12
1941	transit	149.674	0.016
1964	radar	149.5981	0.001
1976	telemetry	149.597 870	0.000 001
2009	telemetry	149.597 870 700	0.000 000 003

Once the AU was known precisely, astronomers could move outward to other objects. At the base of the ladder are *fundamental* distance measurements (like the AU), in which distances are determined directly, with no physical assumptions about the nature of the object in question. This fundamental work is done by astronomers specializing in the discipline of *astrometry* – precise astronomical measurements. The AU, then, is the first rung on the distance ladder and becomes a baseline for distances to the nearby stars. Subsequent rungs will eventually depend upon assumptions about the physical state of the object being used.

Parallax

The next rung on the distance ladder comes from *trigonometric parallax*. Parallax is an apparent displacement or difference in the apparent position of an object viewed along two different lines of sight. Triangulation is the technique that uses parallax. This technique can be used only for objects 'close enough' (within about 1000 parsecs) to Earth. The distance unit *parsec* stands for *par*allax *sec*ond – the distance at which the angle subtended by the celestial object is one arcsecond. Figure 2 is a photo of a statue in honor of the parallax method. Astronomers usually express distances in units of parsecs (pc); light-years are used in popular media, but almost invariably values in light-years have been converted from numbers tabulated in parsecs in the original source.

As the Earth orbits around the Sun, the position of nearby stars will appear to shift slightly against the more distant background of stars (this shift is called parallax). These shifts form angles in a right triangle, with 2 AU making the short leg of the triangle and the distance to the star is the long leg. See Figure 3.

The amount of shift is quite small, measuring one arcsecond for an object at a distance of 1 parsec (3.26 light-years), thereafter decreasing in angular amount as the reciprocal of the distance.

Figure 2. Statue of an astronomer and the concept of the cosmic distance ladder by the parallax method, made from the azimuth ring and other parts of the Yale-Columbia Refractor (telescope) (c 1925) wrecked by the 2003 Canberra bushfires which burned out the Mount Stromlo Observatory; at Questacon, Canberra, Australian Capital Territory.

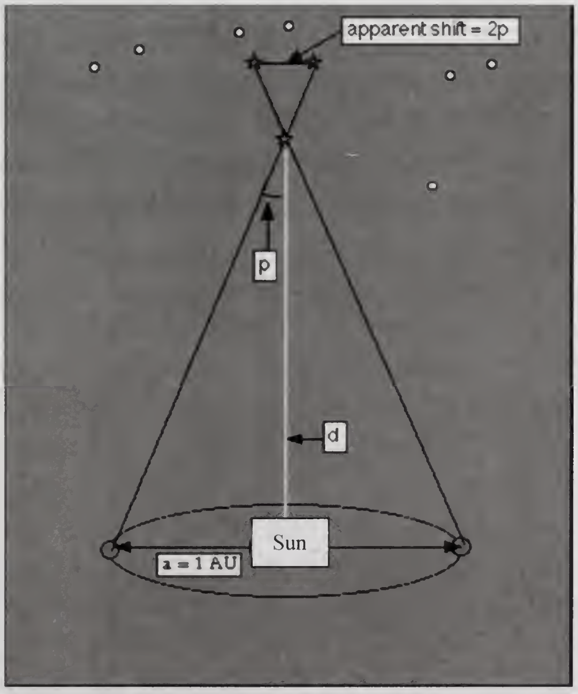

Figure 3. A diagram illustrating astronomical parallax.

Because parallax decreases as distance increases, useful distances can be measured only for stars whose parallax is larger than the precision of the measurement. Stars are quite distant, so observations of the tiny parallax awaited the development.of precision instrumentation. In fact, the lack of an observed parallax for stars had long been used to 'prove' the Earth's central position in the Universe – not orbiting the Sun. The first stellar parallax (of the star 61 Cygni) was measured by Friedrich Wilhelm Bessel (1784 – 1846) in 1838. He arrived at a parallax of 313.6 milliarcseconds (mas), close to the currently accepted value of 287.18 mas. This was a valuable proof that the Earth orbited the Sun. Bessel is also known for the Bessel functions in mathematical physics.

First done on the ground, and now done in space, parallax measurements typically have an accuracy measured in mas. In the 1990s, HIPPARCOS, an astrometric satellite in Earth orbit (1989 – 1993), had the mission of measuring precise parallaxes. It obtained parallaxes for over a hundred thousand stars with a precision of about a mas, providing useful distances for stars out to a few hundred parsecs.

So the next rung on the ladder has a precision of about a milliarcsecond. The European Space Agency's Gaia mission, due to launch in 2012 and come online in 2013, will be able to measure parallax to an accuracy of 10 microarcseconds. As one moves farther out in space the precision drops. It can never improve. This is an important point. The farther out one goes the greater the uncertainty. Astrometry, as always, forms the basis of the distance ladder. Trigonometric parallax is good for stars to a distance of about 100 parsecs. Overall, this is not very far.

Using the AU as the baseline forms the first and most precise type of parallax: trigonometric parallax. There are others: statistical parallax, secular parallax, moving cluster parallax, and spectroscopic parallax. Cross referencing one method to another allows one to move outward in distance. Overlap between methods is necessary.

The *statistical parallax* comes from a statistical analysis of the motion of stars that are located at about the same distance, are with the same spectral class, and show a similar brightness range. It assumes that the average radial velocity of the set of stars is the same as the average transverse velocity. One can then obtain a mean parallax for that set of stars. This method is useful for measuring the distances of bright stars to about 500 pc.

The *secular parallax* uses the motion of the Sun through space as the baseline. For stars in the Milky Way disk, this corresponds to a mean baseline of about 4 AU/year (this is how far the Sun moves at 16.9 km/s with respect to the local standard of rest). After several decades, the baseline can be orders of magnitude greater than the Earth-Sun baseline used for traditional parallax. However, secular parallax introduces a higher level of uncertainty because the relative velocity of other stars is an additional unknown. When applied to samples of multiple stars, the uncertainty can be reduced; the precision is inversely proportional to the square root of the sample size. As with statistical parallax, this method is useful to a distance of about 500 pc.

Neither of these two methods is useful for individual stars. There are uncertainties in the brightness measures and in the velocity measures. Secular parallax is the better choice when the velocity of the Sun is greater than the average radial velocity of the sample. Statistical parallax is better when the velocity of the Sun is less than the average radial velocity of the sample.

The *moving cluster parallax* uses the motions of individual stars in nearby star clusters (such as the Hyades cluster) to find the distance to the cluster. One assumes that the stars in the cluster are about the same age and about the same distance from Earth. This method gives the Hyades cluster a distance of 45.53 ± 2.64 pc. The average of HIPPARCOS trigonometric parallaxes for Hyades members gives a cluster distance of 46.34 ± 0.27 pc. Thus, when comparing the two methods, one can see that they do not give identical results, even for a nearby object; hence the need for more data. This clearly indicates the loss in precision as one moves outward from Earth.

Spectroscopic parallax is a method useful to a distance of about 10,000 parsecs. When the spectrum of a star is observed carefully, it is possible to determine the surface temperature and the surface gravity of the star. Knowing these two allows us to determine the intrinsic luminosity (the brightness emitted by the star). Knowing the luminosity and the flux (the value received at Earth), one can determine the distance from the inverse square law. However, this only works for 'normal' stars (stars on the main sequence), and any given single object might not be normal. Additionally, this method depends upon theoretical models of stars and is only as good as the models (which are actually rather good).

In astronomy, the brightness of an object is usually given in terms of its absolute magnitude, *M*. This quantity is derived from the logarithm

of its luminosity as seen from a distance of 10 pc. The apparent magnitude, m, (the magnitude as seen by the observer), can be used to determine the distance D to the object in kiloparsecs (where 1 kpc equals 10^3 pc) as follows:

$$5\log_{10}\frac{D}{kpc} = m - M - 5$$

where m represents the apparent magnitude and M represents the absolute magnitude. For this to be correct both magnitudes must be in the same frequency band (*i.e.*, one cannot compare blue magnitudes to red magnitudes) and there can be no relative motion in the radial direction. There is an additional issue with interstellar extinction. The space between stars is not empty. It contains gas and dust which makes distant objects appear fainter and redder than they actually are. One must correct for this. Measurements of the interstellar extinction are part of fundamental astronomy.

The difference between apparent and absolute magnitudes ($m - M$) is called the *distance modulus*, and astronomical distances, especially intergalactic ones, are sometimes tabulated in this way.

As an example of spectroscopic parallax consider the star Spica. Its apparent magnitude is 0.98. Its spectral type[ii] is B1 which means its absolute magnitude can range from -3.2 to -5.0. The distance modulus therefore gives a range in distance of 157.05 to 68.54 pc. HIPPARCOS measurements give a distance of 80.38 pc. Hence the method can work but is not very precise.

Wow, all this work and we have yet to leave the Milky Way, which has a diameter of about 30,000 pc.

Other individual celestial objects can have fundamental distance estimates made for them under special circumstances. If the expansion of a gas cloud, like a supernova remnant or planetary nebula, can be observed over time, then an *expansion parallax* distance to that cloud can be estimated. The distance estimate comes from computing how far away the object must be to make its observed absolute velocity appear with the observed angular motion.

Expansion parallaxes in particular can give fundamental distance estimates for objects that are very far away, because supernova ejecta have large expansion velocities and large sizes (compared to stars). Further, they can be observed with radio interferometers which can measure very

small angular motions. These combine to mean that some supernovae in other galaxies have fundamental distance estimates. Though valuable, such cases are quite rare, so they serve as important consistency checks on the distance ladder rather than workhorse steps by themselves.

The Standard Candle

To move outward in distance one starts with trigonometric parallaxes, then observes the same object with the other types of less precise parallaxes to calibrate and scale them. Once this is done one has the distance ladder reaching about 10,000 pc – halfway across the Milky Way.

At this point one must put aside the parallax method and use other methods. With few exceptions, distances based on direct measurements are available only out to about a thousand pc, which is a modest portion of our own Galaxy. For distances beyond that, measurements are going to depend upon physical assumptions, that is, knowledge of the object in question. One must recognize the object and assume the class of objects is homogeneous enough that its members can be used for a meaningful estimation of distance – a *standard candle* as it were.

Almost all of the remaining rungs on the ladder are standard candles of one kind or another. A standard candle is an object that belongs to some class that has a known brightness (*i.e.*, all members of the class have the same brightness). By comparing the known luminosity of the latter to its observed brightness, the distance to the object can be computed using the inverse square law.

Two problems exist for any class of standard candle. The principal one is calibration, determining exactly what the absolute magnitude of the candle is. This includes defining the class well enough that members can be recognized, and finding enough members with well-known distances that their true absolute magnitude can be determined with enough accuracy. The second lies in recognizing members of the class, and not mistakenly using the standard candle calibration upon an object which does not belong to the class. At extreme distances, which are where one most wishes to use a distance indicator, this recognition problem can be quite serious.

Another significant issue with standard candles is the question of how standard they are. For example, all observations seem to indicate that Type Ia supernovae that are of known distance have the same brightness (corrected by the shape of the light curve); however, the possibility that

the distant Type Ia supernovae have different properties than nearby Type Ia supernovae exists. The use of Type Ia supernovae is crucial in determining the correct cosmological model. If indeed the properties of the Type Ia's are different at large distances, *i.e.* if the extrapolation of their calibration to arbitrary distances is not valid, ignoring this variation can dangerously bias the reconstruction of the cosmological parameters.

That this is not merely a philosophical issue can be seen from the history of distance measurements using Cepheid variables (this technique is described below). In the 1950s, astronomer Walter Baade discovered that the nearby Cepheid variables used to calibrate the standard candle were of a different type than the more distant ones used to measure distances to nearby galaxies. The nearby Cepheid variables were young, massive stars with much higher metal content than the distant old, faint ones. As a result, the old stars were actually much brighter than believed, and this had the ultimate effect of doubling the distances to the globular clusters, the nearby galaxies, and the diameter of the Milky Way.

Cepheids

Now that Cepheids have been mentioned, let me discuss this important class of stars. They are a crucial rung in the distance ladder. Cepheids are luminous variable stars that radially pulsate. The strong direct relationship between a Cepheid's luminosity and its pulsation period makes them an important standard candle for Galactic and extragalactic sources. Type I Cepheids undergo pulsations with very regular periods on the order of days to months.

A relationship between the period and luminosity for Type I Cepheids was discovered in 1908 by Henrietta Swan Leavitt in her investigation of thousands of variable stars in the Magellanic Clouds. Figure 4 is the figure from her discovery paper of 1912.

To use them as standard candles, one observes the pulsation period to get the luminosity (absolute magnitude). By then measuring the apparent brightness (value observed at Earth) one has everything needed to use the distance modulus $m - M$. The work was so important that Leavitt was considered for the Nobel Prize, but she died before her name could be submitted.

One needs a distance measurement from some other method for at least one Cepheid to correlate the class to the distance ladder. The original Cepheid variable, delta Cephei, is close enough that we have a

trigonometric parallax measurement for it. Figure 5 shows the data from HIPPARCOS for delta Cephei.

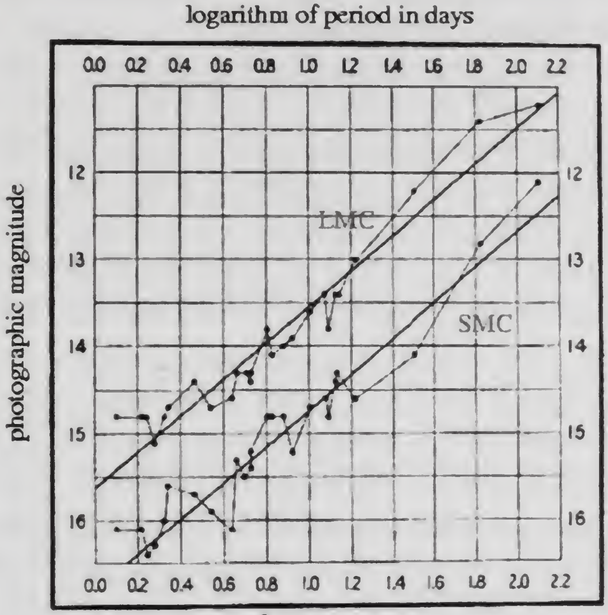

FIG. 2.

Figure 4. (From Leavitt's publication): "In Figure 2 ... a straight line can readily be drawn ... showing that there is a simple relation between the brightness of the variables and their periods.... Since the variables are probably at nearly the same distance from the Earth, their periods are apparently associated with their actual emission of light, as determined by their mass, density, and surface brightness."
--Leavitt (1912)

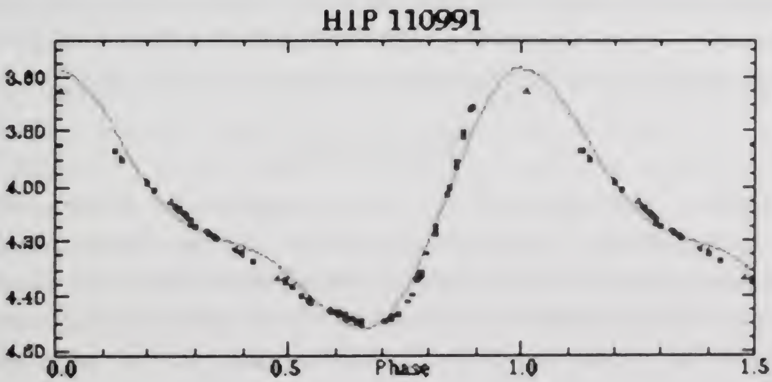

Figure 5. The period luminosity plot for delta Cephei from Hipparcos data. The dots are the observations; the line is the predicted curve.

In addition, using data from the HIPPARCOS astrometry satellite, astronomers calculated the distances to many Galactic Cepheids using the trigonometric parallax technique. The resultant period-luminosity relationship for Type 1 Cepheids was:

$$M_V = -2.81\log(P) - (1.43 \pm 0.1)$$

where M_V is the absolute magnitude and P is the period. The uncertainty is now much greater than the uncertainty for the AU. Once the class is calibrated using Milky Way Cepheids, one can then move out to the nearby Small Magellanic Cloud using Cepheids found there and leap-frog to the Large Magellanic Cloud and outward to the Andromeda galaxy.

To date, NGC 3370, a spiral galaxy in the constellation Leo, contains the farthest Cepheids yet found at a distance of 29 Mpc. Cepheid variable stars are in no way perfect distance markers: for nearby galaxies they have an error of about 7% and up to a 15% error for the most distant.

There are a number of technical issues with Cepheids. Tying down the errors is a difficult process and is on-going. In fact, in 2009 astronomer Allen Sandage said that the existence of a universal period-luminosity relation of classical Cepheids is an only historically justified illusion. Nevertheless they remain an important rung on the distance ladder.

The same principle used for Cepheids applies to RR Lyrae variable stars. RR Lyrae variables are periodic variable stars, commonly found in globular clusters, and often used as standard candles to measure galactic distances. This type of variable is named after the prototype, the variable star RR Lyrae in the constellation Lyra. Once one knows that a star is an RR Lyrae variable (*e.g.*, from the shape of its light curve), then one knows its luminosity. From that one can determine the distance. RR Lyrae stars are useful standard candles for objects within the Milky Way.

Binary Stars

Binary star systems[iii] are very important in astronomy because calculations of their orbits allow the masses of their component stars to be directly determined, which in turn allows indirect estimates of other stellar parameters, such as radius and density. This also determines an empirical mass-luminosity relationship from which the masses of single stars can be estimated. Binaries can sometimes be used as distance indicators.

Binary stars are often detected optically, in which case they are called *visual binaries*. These binaries are seen as two separate stars. Many

visual binaries have long orbital periods of several centuries or millennia and therefore have orbits which are uncertain or poorly known. Binary stars may also be detected by indirect techniques, such as spectroscopy (*spectroscopic binaries*). If a binary star happens to orbit in a plane along our line of sight, its components will eclipse and transit each other; these pairs are called *eclipsing binaries*, or, if they are detected by their changes in brightness during eclipses and transits, *photometric binaries*.

The distance to a visual binary star may be estimated from the masses of its two components, the size of their orbit, and the period of their revolution around one another. A *dynamical parallax* is an (annual) parallax which is computed from such an estimated distance.

In the last decade, the advent of 8 meter class telescopes has enabled the measurement of eclipsing binaries' fundamental parameters (*e.g.*, mass, radius). This makes it feasible to use them as indicators of distance. Recently, they have been used to give direct distance estimates to the Large Magellanic Cloud, the Small Magellanic Cloud, the Andromeda galaxy, and the Triangulum galaxy. These galaxies are in the Local Group – the group of galaxies that contains our Milky Way. Eclipsing binaries offer a direct method to gauge the distance to galaxies to a new improved 5% level of accuracy out to a distance of around 3 Mpc.

Andromeda is about 778 kpc from the Milky Way. Astronomers first used an eclipsing binary to determine the precise distance to the Andromeda galaxy in 2005. This distance is in excellent agreement with other, less direct determinations. The binary, known as M31VJ00443799+4129236 (I had to share the name!), has two hot blue stars of spectral types O and B. As the stars orbit each other every 3.54969 days, they pass in front of and behind each other.

By comparing the absolute and apparent magnitudes of the two stars, the astronomers concluded the Andromeda Galaxy is 2.52±0.14 million light-years from Earth. This agrees perfectly with the Cepheid-based distance to Andromeda: 2.5 million light-years. The distance, however, does not depend on first assuming a distance to the Large Magellanic Cloud and leap-frogging from there. The agreement means astronomers can probably trust Cepheid distances to more distant galaxies, such as those in the Virgo and Fornax clusters.

Nevertheless the uncertainty is now at the 5% level.

Beyond Cepheids

A succession of distance indicators, which is the distance ladder, is needed for determining distances to other galaxies. Objects bright enough to be recognized and measured at large distances are so rare that few or none are present nearby, so there are too few examples close enough with reliable trigonometric parallax to calibrate the indicator. For example, Cepheid variables, one of the best indicators for nearby spiral galaxies, cannot be satisfactorily calibrated by trigonometric parallax alone. There are not enough overlapping stars. The situation is further complicated by the fact that different stellar populations generally do not have all types of stars in them. Cepheids in particular are massive stars, with short lifetimes, so they will only be found in places where stars have very recently been formed. Consequently, because elliptical galaxies usually have long ceased to have large-scale star formation, they will have few or no Cepheids. Instead, distance indicators whose origins are in an older stellar population (like RR Lyrae variables) must be used. However, RR Lyrae variables are less luminous than Cepheids (so they cannot be seen as far away as Cepheids can).

Because the more distant steps of the cosmic distance ladder depend upon the nearer ones, the more distant steps include the effects of errors in the nearer steps, both systematic and statistical ones. The result of these propagating errors means that distances in astronomy are rarely known to the same level of precision as measurements in the other sciences, and that the precision necessarily is poorer for more distant types of object.

There are still only about 30,000 stars with relative parallax accuracy better than 10%. And these stars are all in the solar neighborhood with few Cepheids and RR Lyraes.

Another concern, especially for the very brightest standard candles, is their "standardness:" how homogeneous the objects are in their true absolute magnitude. For some of these different standard candles, the homogeneity is based on theories about the formation and evolution of stars and galaxies, and is thus also subject to uncertainties in those aspects. For the most luminous of distance indicators, the Type Ia supernovae, this homogeneity is known to be poor; however, no other class of object is bright enough to be detected at such large distances, so the class is useful simply because there is no real alternative.

So where do we go from here? We look at Type Ia supernovae.

Type Ia Supernovae

Figure 6 shows a supernova in the galaxy NGC 4526. The supernova is the bright spot in the lower left. It is, temporarily, as bright as the galaxy. Type Ia supernovae (SN) have a very well-determined maximum absolute magnitude as a function of the shape of their light curve and are useful in determining extragalactic distances up to a few hundred Mpc.

Figure 6. Supernova SN 1994D in the NGC 4526 galaxy (bright spot on the lower left). Image by NASA, ESA

Type Ia SN are some of the best ways to determine extragalactic distances. Ia's occur when a binary white dwarf star begins to accrete matter from its companion red dwarf star. As the white dwarf gains matter, eventually it reaches its Chandrasekhar Limit of 1.4 $\mathcal{M}_{\odot}$. This is as massive as it can get. Once that limit is reached, the white dwarf star becomes unstable and undergoes a runaway nuclear fusion reaction. Because all Type Ia SN explode at about the same mass, their absolute magnitudes are all the same. This makes them very useful as standard candles. All Type Ia SN have a standard blue and visual magnitude of

$$M_B \approx M_V \approx -19.3 \pm 0.3 .$$

Therefore, when observing a Type Ia SN, if it is possible to determine what its peak magnitude was, then its distance can be calculated. It is not necessary to capture the SN directly at its peak magnitude. Compare the shape of the light curve (taken at any reasonable time after the initial explosion) to a family of parameterized curves to determine the absolute magnitude at the maximum brightness. This method also takes into effect interstellar extinction/dimming from dust and gas. So the method is to

observe the SN to get its apparent brightness at maximum, and since the absolute luminosity is known, use the distance modulus to get the distance.

Using Type Ia SN is one of the better methods, particularly since SN explosions can be visible at great distances (their luminosities rival that of the galaxy in which they are situated), much farther than Cepheid variables (500 times farther). Much time has been devoted to the refining of this method. The current uncertainty approaches a mere 5%, corresponding to an uncertainty of just 0.1 magnitudes.

There are other specialized distance indicators, but they are typically empirical and lack a robust underpinning.

Future Possibility

The D-σ relation, used in elliptical galaxies, relates the angular diameter (D) of the galaxy to its velocity dispersion (σ). The observed velocity dispersion is the result of the superposition of many individual stellar spectra, each of which has been Doppler shifted because of the star's motion within the galaxy. Therefore, σ can be determined by analyzing the integrated spectrum of the whole galaxy; the galaxy integrated spectrum will be similar to the spectrum of the stars which dominate the light of the galaxy, but with broader absorption lines due to the motions of the stars. The velocity dispersion is a fundamental parameter because it is an observable that better quantifies the potential well of a galaxy.

The parameter D is, more precisely, the galaxy's angular diameter out to the surface brightness level of 20.75 B-mag arcsec^{-2}. This surface brightness is independent of the galaxy's actual distance from us. Instead, D is inversely proportional to the galaxy's distance. This relation between D and σ is:

$$\log_{10}(D) = 1.333\log(\sigma) + C$$

where C is a constant which depends on the distance to the galaxy clusters.

This method has the possibility of becoming one of the strongest methods of extragalactic distance calculators. As of today, however, elliptical galaxies aren't bright enough to provide a calibration for this method through the use of techniques such as Cepheids. So instead calibration is done using cruder methods like supernovae.

Conclusion

The purpose of the ladder is to obtain the Hubble Constant, H_0. Hubble observed that the fainter the galaxy the more its spectra was redshifted. Figure 7 shows Hubble's original plot. Finding the value of the Hubble constant was the result of decades of work by many astronomers, both in amassing the measurements of galaxy redshifts and in calibrating the steps of the distance ladder. Hubble's Law relates redshift to distance and is the primary means we have for estimating the distances of quasars and distant galaxies in which individual distance indicators cannot be seen. The redshift, z, is given by the shift in the spectral line:

$$z = \frac{\lambda_0}{\lambda} - 1, \text{ and}$$

$$cz = H_0 d$$

where d is the distance. So if one can measure the redshift, z, then one can determine the distance.

A 2011 determination of H_0 is $H_0 = 73.8 \pm 2.4$ (km/s)/Mpc. By linking Cepheid observations in the galaxy NGC 4258 with those in host galaxies of supernovae, this recent determination claims to reduce the error to less than 5%. The age of the Universe is inversely proportional to H_0. This puts an uncertainty of about ±0.1 billion years for the age of the Universe.

After all this we realize that the age of the Universe and the Hubble constant ultimately depend upon that first rung of the ladder determined by astronomers who work in the field of astrometry. Figure 8 is an old cartoon showing this dependence. It does not really overstate the case. Errors in the cosmic distance ladder do indeed increase with distance. As one ascends the ladder, the more precise the preceding rung is, then the more precise the next link will be.

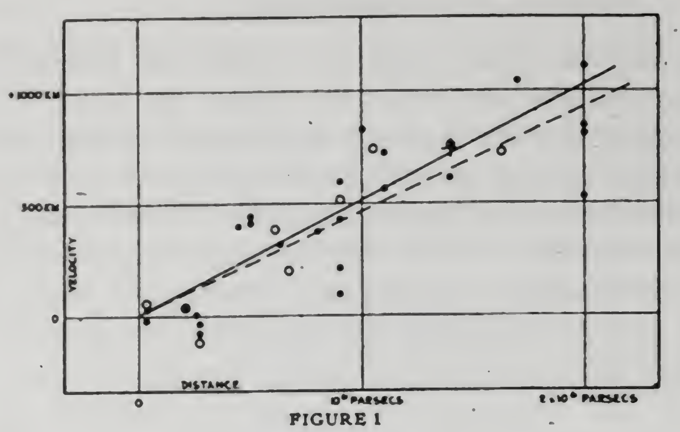

FIGURE 1

Figure 7. Hubble's original plot relating redshift (y axis) to distance (x axis)

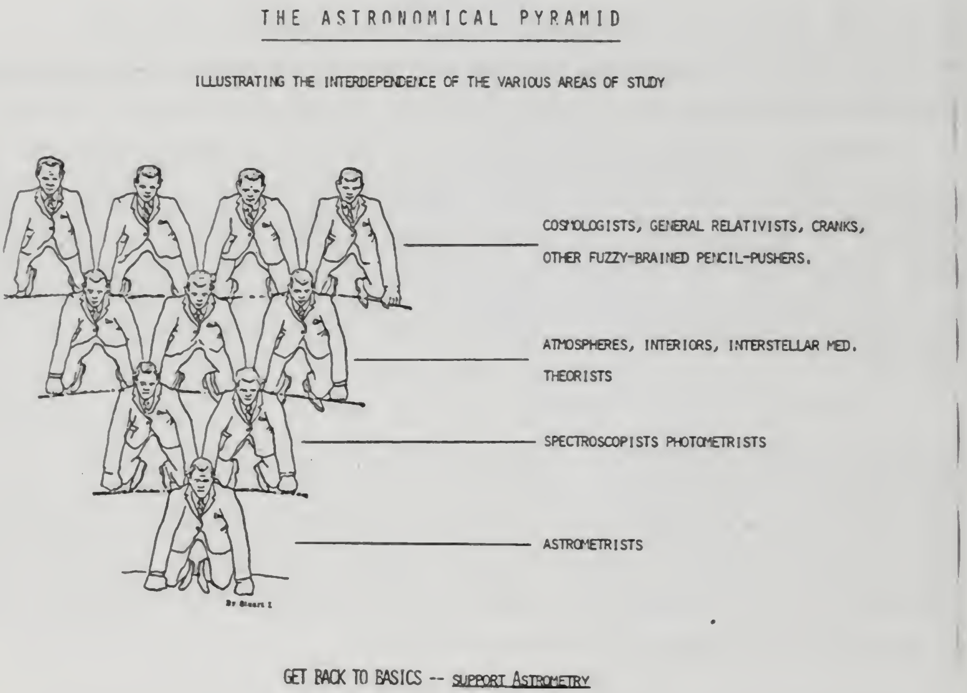

Figure 8. The only problem I have with this cartoon is that they are all men!

---

[i] John J. O'Connor, Edmund F. Robertson (1999). Abu Arrayhan Muhammad ibn Ahmad al-Biruni, *MacTutor History of Mathematics archive*, U. St. Andrews, Scotland.

[ii] This is a scale based on the spectrum that runs from hot (O stars) to cool (M stars). The scale has seven levels: OBAFGKM. Each level defines a range of absolute magnitudes.

[iii] These are stars that orbit each other.

Outgoing President's Remarks
WAS Awards Banquet – May 2011
Mark Holland

Greetings to all: Ladies and Gentlemen, WAS members, distinguished awardees, honored guests. The awards banquet is one of the highlights of the Washington Academy calendar. Allow me to begin by thanking all of the many people responsible for putting together this evening's program and handling the logistics: the WAS banquet and Awards Committees and our Executive Director, Peg Kay. We thank you all for your hard work.

The founding fathers of the WAS established the Academy for the purpose of "encouraging scientific endeavor in all its forms." As this year's Academy President, I suppose that makes me the 113th head cheerleader for the Washington area science team. We have a lot to cheer about. It still amazes me that within our relatively small geographic area, more than 60 scientific societies and institutions are affiliated with the WAS. What a vital atmosphere and what fertile ground for the scientific endeavor!

During the past year, the Academy continued its long-standing support of junior scientists through the activities of the Junior Academy and STARS program. It is wonderful to see that Dick Davies has so ably taken over the reins of this program from Paul Hazen and that it is thriving. Congratulations to Dick and to Paul for a job well done. Last fall

we sponsored a lecture by Capt. Phillip Renaud of the Living Oceans Foundation on their work charting reef communities. We also presented a second installment of our "Science is Murder" series, a panel discussion by popular mystery writers who incorporate science themes in their work. Both of these programs were well attended and well received. The affiliates' reception, held in November at AAAS, featured a talk by Dr. Gene Williams, our Vice President for Affiliated Societies, on a scientific expedition to Iceland.

Of all our activities during 2011, the one that makes me the most happy is the establishment of College and University Chapters of the Washington Academy. With the establishment of these chapters, the Academy has a mechanism for reaching out to the next generation of scientists and welcoming them into the profession. I encourage any of you here in the audience this evening with ties to a local college or university to consider starting an Academy Chapter. Please contact me for additional information. The upcoming CapSci meeting in 2012 will be a great opportunity for our college and university students to showcase their work and make contact with working professionals whose scientific interests mesh with their own.

Finally, I invite each of you and the societies you represent to take an active role in the work of the WAS. We cheerleaders of the Academy are here to encourage the scientific endeavor. Help us as active participants to identify ways in which we can be more supportive of your work and the collective work of our scientific community.

Thank you to the Academy and to all of you for your encouragement and support during the past year. I look forward to continuing to work with the Academy and our next President (head cheerleader), Gerry Christman.

AWARDEES

Physical Sciences.
Gerald Fraser

Social and Behavioral Sciences
Gary E. Machlis

Health Sciences
Naomi L. Corman Luban

Biological Sciences
Mina Izadjoo

Leo Schubert Award for the Teaching of Science in College
David L. Trauger

Engineering Sciences
Neal F. Schmeidler

Banquet Speaker
Sam Kean

Can the Periodic Table Tell a Story?!

May 12, 2011

Minutes by Ron Hietala of Sam Kean's Talk

On the occasion of the Annual Meeting and Award Ceremony of the Washington Academy of Sciences, Dr. Jacqueline Maffucci introduced Sam Kean, the featured speaker. Mr. Kean is a correspondent for *Science* magazine and recently published his first book, *The Disappearing Spoon and other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements* (Little, Brown, 2010). The book has received very favorable reviews and comments. Briefly, reviewers find it, as do I, an unusually good read and a fun, interesting book about science, especially science history. Mr. Kean's address to the Academy was also a recount of tales from the Table.

When a kid in the third grade or so Mr. Kean had a streak of strep throat infections. He stayed home from school for several periods. His mom took his temperature with an old fashioned thermometer, and more than once, Mr. Kean, who says he was a clumsy kid, dropped it and broke it. He was secretly excited by this. Brilliant spheres of mercury scattered about the floor. His mother got down with a toothpick to scoot the blobs together. It was cause for wonder how two blobs would come close together, and, with a jiggle, jump into one slightly larger blob. Mercury

was so neat that the Keans kept it in a little pill bottle. Sam's mother would get it down sometimes and show it to the kids. That was how he got started on the Periodic Table.

When they gave him the Table in school, he looked for mercury and did not find it. When he learned the symbol for mercury was Hg, he found that really strange; neither of those letters actually occurs in the word, mercury. He asked around about it and found the letters come from Latin and Greek words.

This led to further inquiry. He found the element had been known since ancient times. There was a god with the same name and a planet named for it. Alchemists used mercury in their experiments and demonstrations.

Nearer home, Mr. Kean found some more history involving mercury. In South Dakota, they always had a long section of history courses devoted to Lewis and Clark. Benjamin Rush, a physician who was also one of the signers of the Declaration of Independence, supported the Expedition. Rush stayed behind to fight a yellow fever epidemic but did leave a mark by assisting them nevertheless.

One of Rush's favorite treatments was a mercury chloride sludge. He prescribed this often, sometimes until his patients' hair and teeth fell out and they drooled. He also had a patented mercuric pill called "Dr. Rush's Bilious Pills." About four times the size of an aspirin, 600 of them went with Lewis and Clark. They were powerful laxatives, popularly referred to as thunderclappers, and Rush encouraged their liberal use. They flushed people's systems very effectively. Historians and archeologists today can pinpoint the locations of some Lewis and Clark camps by concentrations of mercury in the soil.

From this one element, Mr. Kean said, he learned much beyond chemistry. He learned about history, alchemy, entomology, poisons, and psychology. He gravitated toward the teachers who told stories that included such broad context with their material, and that was the pattern he followed in *The Disappearing Spoon.*

Take aluminum, for instance. Today it is one of the most common metals. For a long time, it was more precious than silver and gold. This was because it was very hard to get it purified, to separate it from the oxygen. When scientists did start to get it, it was considered miraculous; it was light, strong, and beautiful. Kings and emperors wanted it. Mr. Kean showed a picture of an aluminum sculpture used by Napoleon III as a centerpiece. Gold items held places off the center. Napoleon III also had

an aluminum cutlery set used by his most important guests, while less favored guests used the gold pieces. The top of the Washington Monument was finished with a small square of aluminum, to show the wealth of the developing nation in 1884.

Not long after that, chemists figured out how to separate aluminum efficiently. One of the chemists, Charles Martin Hall, formed a company called Alcoa, which started shipping aluminum at the breathtaking rate of 50 pounds a day. The price of aluminum dropped quickly from dozens of dollars an ounce to 25 cents a pound.

So aluminum has all the elements of a great story. It had a romantic history, a breakthrough development, and a great change in practice. Finally, it had a new and changed state of being. Your interpretation may depend on your temperament, whether aluminum was better off as a precious metal or a useful metal.

Cadmium has a similar story arc. Early on, it found use as a pigment to make red and yellow paints. Painters favored the vibrant cadmium colors. In Japan about the time of WWI, they were refining zinc. Cadmium has similar properties to zinc, and some of the processes yielded cadmium that contaminated the zinc. When they got the cadmium separated, they dumped it in the streams. It followed the streams down to the rice paddies. Rice, it seems, is a cadmium sponge, and farm families soon experienced problems including kidney disease, pain and brittle bones. One woman reportedly had her wrist broken by a doctor taking her pulse. They called it itai-itai (ouch-ouch) disease, for the pained shouts of the afflicted.

A local doctor figured out that what was happening was chronic cadmium poisoning. A long and tortuous civil action resulted in a large settlement for the victims, and cadmium became a symbol for evil in Japan.

Even in the 1980's, in making another in the Godzilla series of movies, the evils of cadmium were summoned. To kill off Godzilla, the heroes used missiles tipped with cadmium. Cadmium, even in 1980, was the nastiest thing they could imagine. Considering that Godzilla was himself the biological accident of an H-bomb explosion that is quite a distinction for cadmium.

Mr. Kean speculated that, had he given this talk a title, it might have been, "... can the Periodic Table tell a story...." Not, "Can the Periodic Table Tell a Story?" but, "Boy, Can the Periodic Table Tell a Story!" You can really learn a lot of science from the Periodic Table. People remember and absorb better what they learn through stories. The personalities of the people also tell us things.

People eat and breathe the Periodic Table. They bet huge sums of money on it. Philosophers use it to probe the meaning of science. It even spawns wars sometimes.

During the cold war, the Periodic Table was a contested field. Science was then acknowledged to be led by European scientists, who viewed Americans as upstarts. Elements then discovered might have been named for Alabama, Illinois, or Virginia, where they were discovered. The European scientists who were in charge then did not trust the American claims. Later European scientists found these elements and named them things like Francium. After WWII, however, Americans, especially the Berkeley group, started filling in box after box after box.

When the Soviets got going in science during the cold war, they generally had the support of Stalin. That was with the exception of the new variety of physics. Stalin, who considered himself an intellectual authority on just about everything, was suspicious of the developing sciences of relativity and quantum mechanics. He wanted them gone. He thought they were spooky and counterintuitive. He was planning to order the purge when he was told by a brave adviser that this might hurt the nuclear weapon program. Stalin thought about that a few seconds and then said, "Leave the physicists in peace; we can always shoot them later." On that basis, Soviet atomic physics moved ahead apace.

Soviet scientists were more comfortable studying elements. These new elements had obvious value and obvious validity. Their accomplishments were ones that the whole Soviet Union could be proud of. They did make progress, and in 1963, they finally beat the Americans at what had become the Americans' game; they discovered an element before the Americans did.

Then, the Americans treated the Soviets the same way the Europeans had treated the Americans. The Americans refused to admit the validity of the proof of the new element. Subsequent discoveries were contested at length

and with strength, and the disputes over who had discovered them outlasted the cold war.

The Americans managed to get one named Seaborgium, after Glenn Seaborg. This seemed quite boorish elsewhere in the world, as the tradition had been that you had to be dead before you could enjoy such an honor. Mr. Kean showed a picture of Mr. Seaborg as an elderly, smiling cherub looking proudly at his box, box 106, on the Table. New rules were made after that, and if they last, Mr. Seaborg will be the only living man ever so fortunate as to have his name in the Table. Mr. Kean calls the Table "the most limited real estate in science," as there are only 100 plus a few spaces on it.

In writing *The Disappearing Spoon*, Mr. Kean spoke to many scientists, some of whom had not looked at the Table in decades. Some were surprised at how much this very fundamental construct had changed. It used to be only eight boxes wide. Some elements did not even rate their own box; they shared one with another element across a diagonal line. Many elements have been added.

One might wonder, are they going to discover more elements? Presumably so. The most recent one was added only a little over a year ago. It is called by a temporary name, ununseptium, which is Latin for 117. It filled the bottom row and made the Table a perfect rectangle, and that may be the last time that occurs, also. The larger elements are very fragile and last a few seconds at most, so discovery is likely to be more haphazard from this point forward.

The Table has been pictured in many ways. It has been portrayed as a galaxy, as board games, as a sort of double helix, maps, mobius strips, and even as a Rubik's cube. (That last one was patented.) Mr. Kean found one woman who went to a photomat and made about 120 pictures of herself. She used them to decorate a Periodic Table which she keeps on her refrigerator. Mr. Kean doesn't know how some of these unorthodox Tables are useful, but he is pleased that people continue to tinker with the Table.

Finally, Mr. Kean pointed out that the Table, in addition to being a very compact scientific heuristic, has implications that are very broad. Astro-scientists have searched for ways to try to communicate with intelligent life elsewhere in the universe. This is a tough question, since these beings would likely share little of our culture. How could we communicate with them: what might we have in common with them? Various ideas were

offered, such as prime numbers and pi, the relationship of the circumference of a circle to its diameter. Mr. Kean liked the notion of using the Periodic Table. There are only 100-some elements in the universe and it seems likely intelligent beings would know of them. It is a literally universal concept, perhaps the most nearly perfectly universal concept we know, and the elements are arranged the same everywhere.

After the talk, Mr. Kean offered to answer questions and sell books. The appreciative audience took both offers.

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Letter from the Editor

As the school year begins, I want to take a moment to commend all of our members who serve as mentors to the next generation of scientists. We all know the importance of encouraging young students to pursue the sciences. The Washington Academy of Sciences has been actively engaged in this through various programs, including the Junior Academy and CapSci. I want to extend this to the Journal and encourage you to look upon the Journal as another tool to entice students to enter the world of research. I would like to devote an issue each year, or perhaps a section each issue, towards student publications. We at the Journal are happy to work with students to develop ideas, language, and anything else that they might need, and in the end, we'd like to showcase their talents. We welcome all genres of manuscript, to include primary research, literature reviews, opines, or other. We are happy to entertain suggestions. I ask you to please help me by encouraging your students to pursue this opportunity to publish. I am sure that not only will it benefit our students, but our readers as well.

With that, I give you the Fall 2011 *Journal of the Washington Academy of Sciences*. We offer four articles. The first article is a general overview of environmental trends as studied by The Millennium Project and reported in their *State of the Future-2011* report. Once we have you thinking about these overall trends, we then travel to the ocean to learn about the research mission of The Global Reef Expedition. This is a truly amazing project that has cross-cultural cooperation to study the coral reefs, so as to understand the extent of damage to these structures, in the hopes that we can then help to protect them. Following this, *Exoplanets* takes us in the opposite direction to learn about the meticulous science behind the search for planets. Finally, we end where I began this letter, with an article entitled *Innovations in STEM Education*.

We hope that you enjoy.

Jacqueline Maffucci
Editor, The Journal of the Washington Academy of Sciences

Foreword

The following paper is an offering by the Reverend Frank Haig, SJ. Rev. Haig is an emeritus professor of physics at Loyola University, Baltimore. He is a long time member of the Academy, serves on the Board, and is an active supporter of all Academy activities. He has published in the Journal before, most recently in 2006, Volume 92-2: "The Role of Academies of Science in the Critical Examination of New Ideas: Looking at Gaia."

His brother was General Alexander Haig. General Haig served his country in many capacities. He was the Secretary of State under President Ronald Reagan and White House Chief of Staff for President Richard Nixon. He served as Vice Chief of Staff of the Army, the second-highest ranking officer in the Army, and as Supreme Allied Commander Europe commanding all US and NATO forces in Europe. A veteran of the Korean and Vietnam Wars, General Haig was a recipient of the Distinguished Service Cross, the Silver Star with oak leaf cluster, and the Purple Heart.

Rev. Haig generously donated a portion of General Haig's estate to the Academy to be used for office operating funds. The Academy is more than grateful for this donation and asked Rev. Haig to write the following article for the Journal in honor of his brother.

The Dedicatory Gift for the Office of the Washington Academy of Sciences

The Reverend Frank Haig, SJ

Loyola University

THE ESTATE OF GENERAL ALEXANDER MEIGS HAIG, Junior, has made a special bequest to endow the expenses of the office of the Washington Academy of Sciences. Naturally one would like to know why General Haig is associated with such a gift and what its meaning could be.

General Haig was a soldier but a soldier in the American tradition. So was George Washington. So was Dwight Eisenhower. So was George Marshall. All of these wanted to protect not just the physical security of our country but also a whole way of life and culture.

In thinking about this situation I would like to do something a bit out of the ordinary for a scientific journal. I would like to present the homily given on the occasion of the funeral of General Haig. If we consider the occasion and the location we can understand that the words are more religious in tone than would be the norm for a scientific publication. I beg your indulgence on that point because the talk really tells us something profound about General Haig and why he would be delighted to support the Washington Academy of Sciences and its activities.

The Funeral Homily for General Alexander M. Haig, Jr. March 2, 1910

In the modern Catholic tradition there are three readings presented at a funeral liturgy. Let us take a sentence from each and see how they give us light and hope and some insight into the career of Alexander Haig.

First, the prophet Isaiah proclaims: "On this mountain he will destroy the veil that veils all peoples."

And Our Lord says: "A city set on a hill cannot be hidden."

And Saint Peter announces: " ... you rejoice with inexpressible joy touched with glory, because you are achieving faith's goal, your salvation."

What is that veil that veils all peoples, the web that is woven over all nations, of which the prophet speaks? Isaiah, like every sacred poet, I

would imagine, does not want to limit our thoughts. And so, he is probably examining ignorance, sin, and death. Alexander Haig held firmly to the ideals of the American tradition. He believed in the enlightenment that suffuses our great documents. He strove against the sins of treason and cowardice. It may sound strange to hear but as a soldier he was against war and wanted peace. In one famous action in North Korea as a young captain he saved 14,000 people. His dream was a dream of peace although not peace through weakness.

He always thought that the way to bring other peoples to the wisdom of our democratic system was for our nation to be a city set on a hill. Democracy is not sold by having bigger guns than others. It is made attractive by showing a life and a culture that others would freely want to share.

And so, we come to that wonderful expression of Saint Peter in our second reading: "joy touched with glory."

Whose joy are we speaking of? Well, first, Al's joy at a life lived with honor and dignity; our joy in looking at a career that honors our country and our church; our nation's joy at the lifework of one of its outstanding leaders.

It is not a simple joy. All the faithful have a joy if they live a life inspired by the Spirit of Christ. You can see that truth in Al's life with his family, with his wonderful wife Patricia and his children, Alex and Brian and Barbara. In addition, that joy leads the faithful close to Christ and His Father. It is a joy that is rich and fruitful and luxuriant and even extravagant. A joy touched with glory.

Al Haig was a splendid soldier, a brilliant and effective business leader, a citizen who understood the classic trio of family, faith, and flag, a profound patriot, the sort of public servant every nation prays to have and rejoices when that prayer is favorably answered.

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AFFILIATED INSTITUTIONS

The National Institute For Standards and Technology
Meadowlark Botanical Gardens
The John W. Kluge Center of the Library of Congress
Potomac Overlook Regional Park
Koshland Science Museum
American Registry of Pathology
Living Oceans Foundation

Foreword

The Millennium Project was founded in 1996 after a three-year feasibility study with the United Nations University, Smithsonian Institution, Futures Group International, and the American Council for the UNU. It is now an independent non-profit global participatory futures research think tank of futurists, scholars, business planners, and policy makers who work for international organizations, governments, corporations, NGOs, and universities.

The Millennium Project manages a coherent and cumulative process that collects and assesses judgments from over 2,500 people since the beginning of the project selected by its 40 Nodes around the world. The Millennium Project has been scanning a variety of sources to produce monthly reports on emerging environmental issues with potential security or treaty implications. More than 300 items have been identified during the past year and about 2,000 items since this work began in August 2002. The full text of the items and their sources, as well as other Millennium Project studies are included in Chapter 9 on the CD and are available at cost on The Millennium Project's Web site. The work is distilled in its annual *State of the Future*, *Futures Research Methodology* series, and special studies. The following is excerpted from the *2011 State of the Future Report* available from www.millenniumproject.org.

The *2011 State of the Future* ends with some brief conclusions. The readers are invited to draw their own conclusions and share them at mp-public@mp.cim3.net (after signing up at http://www.millennium-project.org/millennium/mp-public.html). The Millennium Project is on LinkedIn and Twitter @MillenniumProj.

2011 State of the Future - Analysis Summary

Excerpted by: Jim Disbrow
Principles: Jerome Glenn, Theodore Gordon, Elizabeth Florescu
Millennium Project

THE WORLD IS GETTING RICHER, healthier, better educated, more peaceful, and better connected and people are living longer, yet half the world is potentially unstable. Food prices are rising, water tables are falling, corruption and organized crime are increasing, environmental viability for our life support is diminishing, debt and economic insecurity are increasing, climate change continues, and the gap between the rich and poor continues to widen dangerously.

There is no question that the world can be far better than it is—IF we make the right decisions. When you consider the many wrong decisions and good decisions not taken—day after day and year after year around the world—it is amazing that we are still making as much progress as we are. Hence, if we can improve our decision making as individuals, groups, nations, and institutions, then the world could be surprisingly better than it is today.

Now that the Cold War seems truly cold, it is time to create a multifaceted compellingly positive view of the future toward which humanity can work. Regardless of the social divisions accentuated by the media, the awareness that we are one species, on one planet, and that it is wise to learn to live with each other is growing, as evidenced by the compassion and aid for Haiti, Pakistan, and Japan; the solidarity with democracy movements across the Arab world; the constant global communications that connect 30% of humanity via the Internet; and the growing awareness that global climate change is everyone's problem to solve.

Fifty years ago, people argued that poverty elimination was an idealistic fantasy and a waste of money; today people argue about the

best ways to achieve that goal within 50 years. Twenty-five years ago, people thought that civilization would end in a nuclear World War III; today people think everyone should have access to the world's knowledge via the Internet, regardless of income or ideology.

The *2011 State of the Future* offers no guarantee of a rosy future. It documents potentials for many serious nightmares, but it also points to a range of solutions for each. If current trends in population growth, resource depletion, climate change, terrorism, organized crime, and disease continue and converge over the next 50 – 100 years, it is easy to imagine an unstable world with catastrophic results. If current trends in self-organization via future Internets, transnational cooperation, materials science, alternative energy, cognitive science, inter- religious dialogues, synthetic biology, and nanotechnology continue and converge over the next 50 – 100 years, it is easy to imagine a world that works for all.

The coming biological revolution may change civilization more profoundly than did the industrial or information revolutions. The world has not come to grips with the implications of writing genetic code to create new lifeforms. Thirteen years ago, the concept of being dependent on Google searches was unknown to the world; today we consider it quite normal. Thirteen years from today, the concept of being dependent on synthetic life forms for medicine, food, water, and energy could also be quite normal.

Computational biophysics can simulate the physical forces among atoms, making medical diagnostics and treatment more individually accurate. Computational biology can create computer matching programs to quickly reduce the number of possible cures for specific diseases, with millions of people donating their unused computer capacity to run the matching programs (grid computing). Computational media allows extraordinary pixel and voxel detail when zooming in and out of 3D images. Computational engineering brings together the world's available information and computer models to rapidly accelerate efficiencies in design. All these are changing the nature of science, medicine, and engineering, and their acceleration is attached to Moore's law; hence, computational everything will continue to accelerate the knowledge explosion. Tele-medicine, tele-education, and tele-everything will connect humanity, the built environment, and computational everything to address our global challenges.

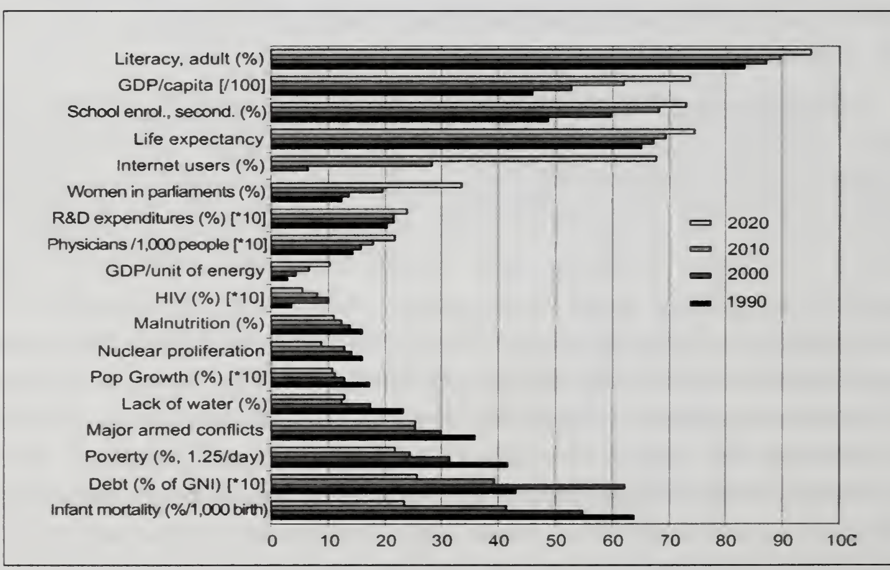
The earthquakes, tsunamis, and nuclear disasters in Japan exposed the need for global, national, and local systems for resilience—the capacity to anticipate, respond to, and recover from disasters while identifying future

technological and social innovations and opportunities. Related to resilience is the concept of collective intelligence—maybe the "next big thing" to help us make better decisions.

After 15 years of The Millennium Project's global futures research, it is increasingly clear that the world has the resources to address its challenges. What is not clear is whether the world will make good decisions fast enough and on the scale necessary to really address the global challenges. Hence, the world is in a race between implementing ever-increasing ways to improve the human condition and the seemingly ever-increasing complexity and scale of global problems.

So, how is the world doing in this race? What's the score so far? A review of the trends of the 28 variables used in The Millennium Project's global State of the Future Index provides a score card on humanity's performance in addressing the most important challenges; see Box 1 and Figures 1 and 2. Some data in Figures 1–3 had to be adjusted for graphic illustration purposes; those adjustments are indicated in the respective labels in brackets.

Figure 1. Where we are winning



Box 1. The World Score Card

Where we are winning

1. Improved water source (percent of population with access)
2. Literacy rate, adult total (percent of people age 15 and above)
3. School enrollment, secondary (percent gross)
4. Poverty headcount ratio at $1.25 a day (PPP) (percent of population) (low- and mid-income countries)
5. Population growth (annual percent) (A drop is seen as good for some countries, bad for others)
6. GDP per capita (constant 2000 US$)
7. Physicians (per 1,000 people) (surrogate for health care workers)
8. Internet users (per 1,000 people)
9. Infant mortality (deaths per 1,000 live births)
10. Life expectancy at birth (years)
11. Women in parliaments (percent of all members)
12. GDP per unit of energy use (constant 2000 PPP $ per kg of oil equivalent)
13. Number of major armed conflicts (number of deaths >1,000)
14. Undernourishment (percent of population)
15. Prevalence of HIV (percent of population 15–49)
16. Countries having or thought to have plans for nuclear weapons (number)
17. Total debt service (percent of GNI) (low- and mid-income countries)
18. R&D expenditures (percent of national budget)

Where we are losing

19. Carbon dioxide emissions (kt)
20. Global surface temperature anomalies
21. People voting in elections (percent of population)
22. Levels of corruption (15 largest countries)
23. People killed or injured in terrorist attacks (number)
24. Number of refugees (per 100,000 total population)

Where there is uncertainty

25. Unemployment, total (percent of total labor force)
26. Non-fossil-fuel consumption (percent of total)
27. Population in countries that are free (percent of total global population)
28. Forestland (percent of all land area)

Figure 2. Where we are losing

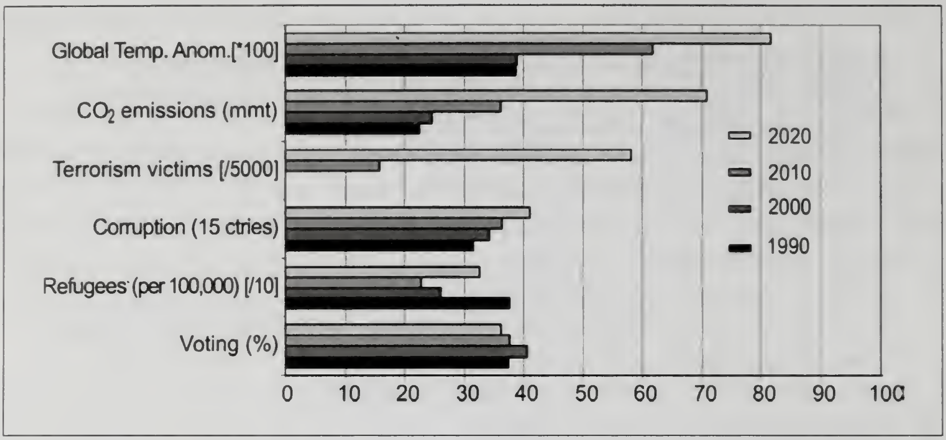


Figure 3. Where trends are not clear

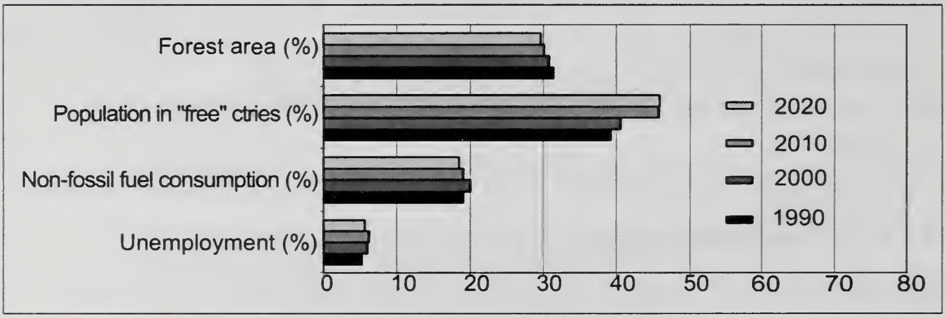
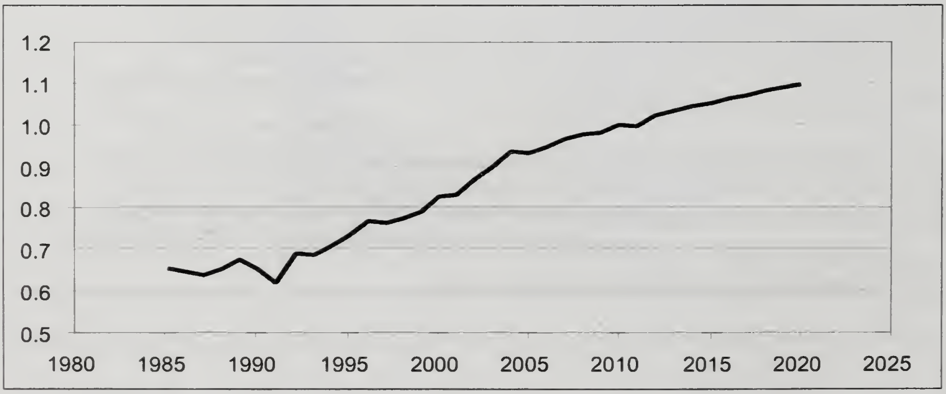
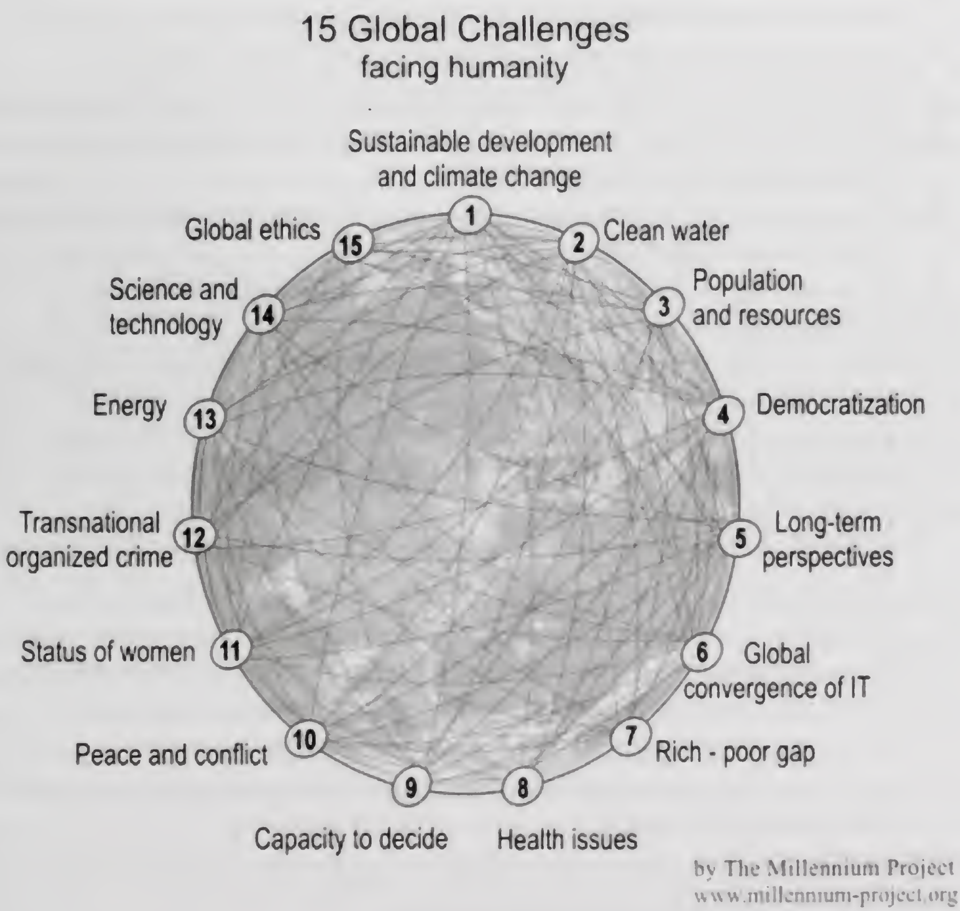


Figure 4. 2011 State of the Future



An international Delphi panel selected over a hundred indicators of progress or regress for the 15 Global Challenges, with some of the driving Key Questions identified below. Indicators were then chosen that had at least 20 years of reliable historical data and later, where possible, were matched with variables used in the International Futures model. The resulting 28 variables shown in Box 1 were integrated into the State of the Future Index (SOFI) with a 10-year projection. SOFIs have also been computed for countries and could be applied to sectors like communications, health, water, and so forth.



Key Questions of the 15 Global Challenges

1. How can sustainable development be achieved for all while addressing global climate change?
2. How can everyone have sufficient clean water without conflicts?
3. How can population growth and resources be brought into balance?
4. How can genuine democracy emerge from authoritarian regimes?
5. How can policymaking be made more sensitive to global long-term perspectives?
6. How can global convergence of information and communications technologies work for everyone?
7. How can ethical market economies be encouraged to help reduce the gap between rich and poor?
8. How can the threat of new and reemerging diseases and immune microorganisms be reduced?
9. How can the capacity to decide be improved as the nature of work and institutions change?
10. How can shared values and new security strategies reduce ethnic conflicts, terrorism, and the use of weapons of mass destruction?
11. How can the changing status of women help improve the human condition?
12. How can transnational organized crime networks be stopped from becoming more powerful and sophisticated global enterprises?
13. How can growing energy demands be met safely and efficiently?
14. How can scientific and technological (S&T) breakthroughs be accelerated to improve the human condition?
15. How can ethical considerations become more routinely incorporated into global decisions?

All questions are addressed in the full version of the 2011 State of the future: http://www.millennium-project.org .

The 2011 SOFI in Figure 4 shows that the 10-year future for the world is getting better. However, in many of the areas where we are winning we are not winning fast enough, such as reductions in HIV, malnutrition, and debt. And areas of uncertainty represent serious problems: unemployment, fossil fuel consumption, political freedom, and forest cover.

Some of the areas where we are losing could have quite serious impacts, such as corruption, climate change, and terrorism. Nevertheless, this selection of data indicated that 10 years from now, on balance, will be better than today.

Some Factors to Consider

Atmospheric CO_2 is at 394.35 ppm as of May 2011, the highest in at least 2 million years. Each decade since 1970 has been warmer than the preceding one; 2010 tied 2005 as the warmest year on record. The world is warming faster than the latest Intergovernmental Panel on Climate Change (IPCC) projections. Even the most recent estimates may understate reality, since they do not take into account permafrost melting.

According to Food and Agriculture Organization (FAO) of the United Nations' (UN) Livestock's Long Shadow report, the meat industry adds 18% of human-related greenhouse gases (GHGs), measured in CO_2 equivalent, which is higher than the transportation industry. A large reinsurance company found that 90% of 950 natural disasters in 2010 were weather-related and fit climate change models; these disasters killed 295,000 people and cost approximately $130 billion.

Humanity's material extraction increased eight times during the twentieth century. Today our consumption of renewable natural resources is 50% larger than nature's capacity to regenerate. In just 39 years, humanity may add an additional 2.3 billion people to world population. There were 1 billion humans in 1804; 2 billion in 1927; 6 billion in 1999; and 7 billion today. China is trying to become the green-growth giant of the world; it is too big to achieve reasonable standards of living for all its people first and then clean up later. Its next Five Year Plan (2011–15) allocated $600 billion for green growth initiatives.

Some believe the global ecosystem is crashing due to climate change, drying rivers and lakes, biodiversity loss, soil erosion, coastal dead zones, and collapsing bee populations unable to fertilize the

food chain. Lester Brown in Plan B 4.0 argues that nothing less than cutting CO_2 by 80% by 2020, keeping population to no more than 8 billion by 2050, restoring natural ecosystems, and eradicating poverty will save the ecosystem, and he proposes lowering income taxes as carbon taxes go up.

Since half of the largest 100 economies in the world are corporations, the former executive secretary of the United Nations Framework Convention on Climate Change (UNFCCC) argues that political leaders must give the business community a more central role in the transition to the green economy.

Falling water tables worldwide and increasing depletion of sustainably managed water have led some people to introduce the concept of "peak water," similar to peak oil. Fossil water – fossil fuels: both will peak, then what? It takes 2,400 liters of water to make a hamburger. Since 1990, an additional 1.3 billion people gained access to improved drinking water and 500 million got better sanitation. Yet 884 million people still lack access to clean water today (down from 900 million in 2009), and 2.6 billion people still lack access to safe sanitation. Half of all hospital patients in the developing world are there for water-related diseases.

As fertility rates fall and longevity increases, the ability to meet financial requirements for the elderly will diminish; the concept of retirement and social structures will have to change to avoid intergenerational conflicts. There were 12 persons working for every person 65 or older in 1950; by 2010, there were 9; and by 2050, the elderly support ratio is projected to drop to 4. There could be 150 million people with age-related dementia by 2050. Advances in brain research and applications to improve brain functioning and maintenance could lead to healthy long life, instead of an infirmed long life.

Food prices are the highest in history and are likely to continue a long-term trend of increases if there are no major innovations in production and changes in consumption, due to the combination of population growth, rising affluence (especially in India and China), the diversion of corn and other grains for biofuels, soil erosion, aquifer depletion, loss of cropland, falling water tables and water pollution, increasing fertilizer costs (high oil prices), market speculation, the diversion of water from rural to urban areas, increasing meat consumption, global food reserves at 25-year lows,

and climate change's increasing droughts and flooding, melting mountain glaciers that reduce water flows, and eventually saltwater invading croplands. New approaches like saltwater agriculture, growing pure meat without growing animals, various forms of agro-ecology to reduce cost of inputs, and increasing vegetarianism would help.

Nearly 30% of the population in Moslem-majority countries is between 15 and 29 years old. Many who are without work and tired of older hierarchies, feeling left behind, and wanting to join the modern world brought change across North Africa and the Middle East this year. This demographic pattern is expected to continue for another generation, leading to both innovation and the potential for continued social unrest and migration.

The social media that helped the Arab Spring Awakening is part of a historic transition from many pockets of civilizations barely aware of each other's existence to a world totally connected via the current and future forms of the Internet. More data went through the Internet in 2010 than in all the previous years combined, and more electronic than paper books were sold by Amazon. Humanity, the built environment, and ubiquitous computing are becoming a continuum of consciousness and technology reflecting the full range of human behavior, from individual philanthropy to organized crime. New forms of civilization will emerge from this convergence of minds, information, and technology worldwide.

The number and percent in extreme poverty is falling. The world economy grew 4.9% in 2010 while the population grew 1.2%; hence, the world Gross Domestic Product (GDP) per capita grew 3.7%. Nearly half a billion people rose out of extreme poverty ($1.25 a day) between 2005 and 2010. Currently this figure is about 900 million or 13% of the world. The World Bank forecasts this to fall to 883 million by 2015 (down from 1.37 billion in 2005). UNDP's new Multidimensional Poverty Index finds 1.75 billion people in poverty. In either case, the number of countries classified as low-income has fallen from 66 to 40. However, the gap between rich and poor within and among countries continues to widen. According to Forbes, Brazil, Russia, India and China (the BRICs) produced 108 of the 214 new billionaires in 2011. There are a total of 1,210 billionaires in the world now, of which 115 are citizens of China and 101 are Russian. The factors that increase the price of food, water,

and energy are increasing; this has to be countered to address world poverty.

The world financial crisis and European sovereign debt emergencies continue to shift power to Asia, yet its leadership has not yet begun to help create that multifaceted general view of the future that humanity can work toward together. China became the second largest economy, passing Japan in 2010, and has more Internet users than the entire population of the United States. By 2030 India is expected to pass China as most populous country in the world. Together these two account for nearly 40% of humanity and are increasingly becoming the driving force for world economic growth.

World health is improving, the incidence of diseases is falling, and people are living longer, yet many old challenges remain and future threats are serious. During 2011 there were six potential epidemics. The most dangerous may be the NDM-1 enzyme that can make a variety of bacteria resistant to most drugs. New HIV infections declined 19% over the past decade; the median cost of antiretroviral medicine per person in low-income countries has dropped to $137 per year; and 45% of the estimated 9.7 million people in need of antiretroviral therapy received it by the end of 2010. Yet two new HIV infections occur for every person starting treatment. Over 30% fewer children under five died in 2010 than in 1990, and total mortality from infectious disease fell from 25% in 1998 to less than 16% in 2010. People are living longer; health care costs are increasing, and the shortage of health workers is growing, making tele-medicine and self-diagnosis via biochip sensors and online expert systems increasingly necessary.

Advances in synthetic biology, mail-order DNA, and future desktop molecular and pharmaceutical manufacturing could one day give single individuals the ability to make and deploy biological weapons of mass destruction. To counter this, advances in sensors to detect molecular changes in public spaces will be needed, along with advances in human development and social engagement to reduce the number of people who might be inclined to use these technologies for mass murder.

Another troubling area is the emerging problem of information and cyber warfare.

Governments and military contractors are engaged in an intellectual arms race to defend themselves from cyberattacks from other governments and their surrogates. Because society's vital systems now depend on the Internet, cyberweapons to bring it down can be thought of as weapons of mass destruction. Information warfare's manipulation of media can lead to the increasing mistrust of all information.

Meanwhile, old style wars have decreased over the past two decades, cross-cultural dialogues are flourishing, and intra-state conflicts are increasingly being settled by international interventions. Today, there are 10 conflicts with at least 1,000 deaths per year (down from 14 last year): Afghanistan, Iraq, Somalia, Yemen, NW Pakistan, Naxalites in India, Mexican cartels, Sudan, Libya, and one classified as international extremism. The U.S. and Russia continue to reduce nuclear weapons while China, India, and Pakistan are increasing them. According to the Federation of American Scientists, by February 2011 there were 22,000 nuclear warheads, of which 2,000 are ready for use by the U.S. and Russia. The number and area of nuclear-free zones is increasing, but the number of unstable states grew from 28 to 37 between 2006 and 2011. Much of Central America could be called a failed or failing state in that organized crime controls people's lives more than governments do. Africa's population could double by 2050, with a growing number of unemployed youth and over 13 million AIDS orphans, increasing the likelihood of social instabilities and future conflicts.

With the potential collapse of Yemen, oil piracy along the Somali coast could increase. Ninety percent of international trade is carried by sea; 489 acts of piracy and armed robbery against ships were reported to IMO in 2010, up from 406 in 2009.

Investments into alternatives to fossil fuels are rapidly accelerating around the world to meet the projected 40–50% increase in demand by 2035.

China has become the largest investor in "low-carbon energy," with a 2010 budget of $51 billion. Three Mile Island, Chernobyl, and now Japan's Fukushima nuclear disasters have left the future of that industry in doubt and strengthened the anti-nuclear movement in Japan and Europe.

Without major breakthroughs in technological and behavioral changes, the majority of the world's energy in 2050 will still come from fossil fuels. Therefore, large-scale carbon capture and reuse has to become a top priority to reduce climate change. Energy efficiencies, conservation, electric cars, tele-work, and reduced meat consumption are near-term ways to reduce energy GHG production. Automakers around the world are in a race to make lower-cost plug-in hybrid and all electric cars. Engineering companies are exploring how to take CO_2 emissions from coal power plants to make carbonates for cement and grow algae for biofuels and fish food. China is exploring tele-work programs to reduce long commuting, energy, costs, congestion.

Empowerment of women has been one of the strongest drivers of social evolution over the past century, and many argue that it is the most efficient strategy for addressing the 15 Global Challenges. Only two countries allowed women to vote at the beginning of the twentieth century; today there is virtually universal suffrage, the average ratio of women legislators worldwide has reached 19.2%, and over 20 countries have a woman head of state or government. Patriarchal structures are increasingly challenged, and the movement toward gender equality is irreversible.

Although the world is waking up to the enormity of the threat of transnational organized crime, the problem continues to grow,

while a global strategy to address this global threat has not been adopted. World illicit trade is estimated at $1.6 trillion per year (up $500 billion from last year), with counterfeiting and intellectual property piracy accounting for $300 billion to $1 trillion, the global drug trade at $404 billion, trade in environmental goods at $63 billion, human trafficking and prostitution at $220 billion, smuggling at $94 billion, weapons trade at $12 billion, and cybercrime costing billions annually in lost revenue. These figures do not include extortion or organized crime's part of the $1 trillion in bribes that the World Bank estimates are paid annually or its part of the estimated $1.5–6.5 trillion in laundered money. Hence the total income could be $2–3 trillion—about twice as big as all the military budgets in the world.

The increasing complexity of everything in much of the world is forcing humans to rely more and more on computers. In 1997 IBM's Deep Blue beat the world chess champion. In 2011 IBM's Watson beat top TV quiz show knowledge champions. What's next? Just as the autonomic nervous system runs most biological decision making, so too computer systems are increasingly making the day-to-day decisions for civilization.

The acceleration of Science and Technology (S&T) continues to fundamentally change the prospects for civilization, and access to its knowledge is becoming universal. Computing power and lowered costs predicted by Moore's Law continues with the world's first three-dimensional computer chip introduced by Intel for mass production.

China currently holds the record for the fastest computer with Tianhe-1, which can perform 2.5 petaflops per second; IBM's Mira, ready next year, will be four times faster.

Is it possible that the acceleration of change will grow beyond conventional means of ethical evaluation? Will we have time to understand what is right and wrong as one change after the next makes it difficult to just keep up? For example, is it ethical to clone ourselves, or bring dinosaurs back to life, or invent new life forms from synthetic biology? These are not remote possibilities in a distant future; the knowledge needed to do them is being developed now. Despite the extraordinary achievements of S&T, future risks from their continued acceleration and globalization needs to be better forecasted and assessed. At the same time, new technologies

also make it easier for more people to do more good at a faster pace than ever before. Single individuals initiate groups on the Internet, organizing actions worldwide around specific ethical issues. News media, blogs, mobile phone cameras, ethics commissions, and Non-Governmental Organizations (NGOs) are increasingly exposing unethical decisions and corrupt practices, creating an embryonic global conscience. Our failure to inculcate ethics into more of the business community contributed to the global financial crisis and resulting recession, employment stagnation, and widening rich-poor gap.

Future Arts, Media, and Entertainment

The explosive, accelerating growth of knowledge in a rapidly changing and increasingly interdependent world gives us so much to know about so many things that it seems impossible to keep up. At the same time, we are flooded with so much trivial news that serious attention to serious issues gets little interest, and too much time is wasted going through useless information. How can we learn what is important to know in order to make sure that there is a good future for civilization? Traditionally, the world has learned through education systems, art, media, and entertainment—and now with advances of communication and entertainment technologies, we have even more information and media at our fingertips on any number of ever-growing delivery systems.

Inspired by the Florentine Camerata Society, a sixteenth-century "think tank" responsible for the creation of the art form we know today as the European opera, The Millennium Project created the Arts and Media Node. The Node invited futuristic artists, media, and entertainment professionals and other innovators around the

world to suggest and discuss future elements or seeds of the future of arts, media, and entertainment. After a month of online discussions, 34 elements were chosen and put into a Real-Time Delphi for an online international assessment. Writers, producers, performing artists, arts/media educators, and other professionals in entertainment, gaming, and communications were nominated by the 40 Millennium Project Nodes around the world to share their views. One distillation of the views of the participants shows that the future of arts, media, and entertainment will be a global, participatory, tele-present, holographic, augmented reality conducted on future versions of mobile smart phones that engage new audiences in the ways they prefer to be reached and involved.

Environmental Security

Environmental security is increasingly dominating national and international agendas, shifting defense and geopolitical paradigms because it is increasingly understood that conflict and environmental degradation exacerbate each other. The traditional nation-centered security focus is expanding to a more global one due to geopolitical shifts, the effects of climate change, environmental and energy security, and growing global interdependencies.

The Millennium Project defines environmental security as environmental viability for life support, with three sub-elements: preventing or repairing military damage to the environment, preventing or responding to environmentally caused conflicts, and protecting the environment due to its inherent moral value.

Conclusion

This year's *State of the Future* is an extraordinarily rich distillation of information for those who care about the world and its future. Since healthy democracies need relevant information, and since democracy is becoming more global, the public will need globally relevant information to sustain this trend. We hope the annual *State of the Future* reports can help provide such information.

The insights in this fifteenth year of The Millennium Project's work can help decision makers, opinion leaders, and educators who fight against hopeless despair, blind confidence, and ignorant indifference — attitudes that too often have blocked efforts to improve the prospects for humanity.

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The Global Reef Expedition: Science without Borders®

Andrew W. Bruckner
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Abstract

The Global Reef Expedition (GRE) is a five year research program to map, characterize and assess the resilience of coral reef ecosystems and develop tools for conservation and management. In 2011, the Khaled bin Sultan Living Oceans Foundation embarked upon a Global Reef Expedition, completing three research projects in the Bahamas (Cay Sal Bank, the Inaguas and Hogsty reef, and Andros and Abaco Islands) and one in St. Kitts and Nevis. Research locations in 2012 include Jamaica, Navassa, Colombia, the Galapagos and French Polynesia, followed by sites off remote Pacific islands, the Coral Triangle, the Indian Ocean and Red Sea. The primary goals of this five year multidisciplinary research and education mission are to map, characterize and assess coral reefs worldwide, educate local communities and stakeholders on the importance of these ecosystems, and provide resource management agencies with tools and information to aid in conservation and management. The GRE targets remote, understudied reefs that are affected minimally by direct human impacts, with comparative work done on coral reefs off populated coastlines. High resolution multispectral satellite imagery (DigitalGlobe's WorldView-2 satellite) is used for navigation, to identify survey sites, and as a platform for habitat characterization. On the ground efforts include (1) the identification and characterization of each habitat type and mapping of the spatial distribution of different habitats; (2) evaluation of the diversity, demographics and health of the species found in these habitats; and (3) characterization of environmental factors and ecological processes that are likely to enhance the resilience of these ecosystems. These data and resulting tools are incorporated into a Geographic Information System (GIS) database and provided to local managers and other stakeholders for use in spatially-based ecosystem management approaches.

Introduction

Shallow water coral reefs are found in tropical areas, roughly between the Tropics of Cancer and Capricorn. They are most prolific in environments with suitable temperatures (16-30° C) and salinity (30-35 ppt), high light penetration, oligotrophic waters with minimal sedimentation and turbidity, and adequate water flow, occurring from just below the water's surface to a maximum of 50–75 m depth. Coral reefs are estimated to cover from 284,300 km^2 (Spalding *et al.* 2001) to about 920,000 km^2 when including associated seagrass beds, mangroves and

other shallow marine habitats (Costanza *et al.* 1997), with 91% of this area in the Indo-Pacific.

Coral reefs are the most complex ecosystem in the marine environment. This complexity is expressed in both the variety of interconnected benthic habitats and a vast array of associated biota, with representatives from 32 of the 34 described animal phyla. At least one-third of all known marine fishes spend at least some portion of their lives in coral reef habitats (Sale 2002). The high diversity is largely due to the heterogeneous nature of coral reef habitat, which can accommodate large size-ranges of reef fishes and numerous functional niches in relatively small areas.

Coral reefs are also one of the few ecosystems that are built upon biogenic substrates created by the dominant organisms found on reefs. The reef substrate consists of limestone originating primarily from the skeletons of stony corals and crustose coralline algae, which has undergone significant modifications in form and area on relatively short time scales. Through grazing activities, bioerosion, and physical breakage during storms, coral skeletons are progressively eroded to produce rubble and sand. Other organisms and a host of chemical, biological, and physical processes cement this material together to form a durable reef substrate, resulting in intricate structures that have enormous surface heterogeneity at a wide variety of spatial scales (Choat and Bellwood 1991).

While the diversity of reef fishes is influenced by the complexity of the reef habitat created by the corals, fishes are also an important, dynamic component of this unique ecosystem. Through interactions at virtually all trophic levels, coral reef fishes modify the reef community structure and help maintain the health of the associated habitat forming corals, and they are major conduits for the movements of energy and nutrients into, within, and out of the reef ecosystem (Hobson 1991; Bellwood and Wainwright 2002). The ecological importance of coral reef fishes also extends beyond the boundaries of the coral habitat. Many reef fishes that are pelagic piscivores and planktivores often feed, and become prey, far away from the coral reef, and the pelagic egg, larval, and juvenile stages form a vast prey resource for predators in oceanic waters.

Coral reefs are a rare but critically important resource. Although they occupy less than 1.2% of the world's continental shelf area and only 0.09% of the total area of the world's ocean, at least 109 countries, territories, and states are directly dependent on the resources and services they provide (Birkeland 1997; Spalding *et al.* 2001). Many economies are

dependent on their products, including sources of protein, biomedical compounds and traditional medicines, and raw materials for construction, as well as their value in terms of employment, recreation, coastal tourism, and coastal protection from storm damage and erosion. Coral reefs are a significant part of many countries natural heritage and are also of great value to the world overall, as they are hotspots of marine biodiversity. Costanza *et al.* (1997) estimated reef ecosystems globally provide US$375 billion each year from living resources and ecosystem services. Nevertheless, the value of reefs is dependent on their continued functioning as ecosystems.

The Global Coral Reef Crisis

Over the past decade, reefs worldwide have witnessed a rapid decline in their health with concurrent losses of corals, declines in fish stocks, and phase shifts from high productivity coral-dominated ecosystems to low productivity algal reefs (Hughes 1994). Recent estimates suggest that 20% of the world's reefs are degraded beyond the potential for recovery, 24% are under imminent risk of collapse and another 26% are under a longer-term threat of collapse (Wilkinson 2008). Furthermore, many of the reefs around the world no longer resemble reefs of 30 years ago.

This global crisis has been attributed to unprecedented and increasing rate by overfishing, use of destructive fishing gear and techniques, land based pollution, coastal development, and other human impacts. These localized human impacts are exacerbated by recent large-scale disturbances associated with climate change, including episodes of mass bleaching, disease outbreaks, plagues of coral-eating predators, and more severe hurricanes (Harvell *et al.* 2007; Baker *et al.* 2008; Rotjan and Lewis 2008). The synergistic effects of these man-made and natural factors are causing dramatic, long-lasting changes in community composition and structure, and concurrent losses of ecosystem services and products from reefs (Hughes 1989, 1994; Knowlton 1992; Aronson *et al.* 2004; McClanahan *et al.* 2007).

The Western Atlantic has been affected most severely by global and local-scale threats and these ecosystems have exhibited the most dramatic declines in coral reef health. Until 1980, Caribbean coral reefs were dominated by three species of corals – large stands of elkhorn coral (*Acropora palmata*) extended for 100s of meters forming dense thickets in the shallow reef crest. In shallow, protected back reef areas and on the tops of reef spurs at depths of 5-15 meters the intertwined branches of the fragile staghorn coral (*Acropora cervicornis*) created complex thickets,

often interspersed with lobate colonies of star coral (*Montastraea annularis*), and providing juvenile habitat and refuge for resting schools of grunts, snappers, and other reef fish. On the fore reef, star coral (*Montastraea annularis* complex) grew into mountainous pinnacles, often 5-10 meter in height or taller, with extensive caves, crevices, and channels between the corals. Deeper, sheets of lettuce coral (*Agaricia lamarki*), star coral, brain corals and other corals with a plating morphology formed overlapping shingles that extended to the base of the reef, at depths of 30-50 m. Many Caribbean reefs had 50-70% living coral cover, with colorful sponges, gorgonians, and other invertebrates filling the spaces between corals.

By the mid-1980s, Caribbean reefs began to change. The long-spined black urchin (*Diadema antillarum*) suffered a Caribbean-wide mass mortality event in 1982-1983. White band disease ravaged stands of elkhorn and staghorn coral, with disease outbreaks spreading throughout the region in the 1980s and 1990s. Since 1995, new diseases have emerged and these are primarily targeting the long-lived, massive corals like star coral. Regional scale coral bleaching first occurred during the 1982-1983 el niño event, and it has progressively increased in severity, with destructive regional and global-scale destructive bleaching events occurring in 1997-1998, 2005 and 2009-2010. Concurrently, overfishing and destructive fishing practices have led to depletion of groupers and other top predators, and a progressive pattern of fishing down the food chain is underway. Terrestrial runoff and land-based pollution are deteriorating water quality, resulting in blooms of fleshy macroalgae that outcompete corals. Poorly managed coastal development projects that include dredging, burial of reefs, and the removal of mangroves and seagrass beds further degrade coral reef habitats and eliminate important nursery areas. These, and a host of other human impacts, are exacerbating the newest and most significant threat to coral reefs – climate change.

Persistence of reefs as coral-dominated systems and continued functioning after large, stochastic perturbations depends on four primary factors: the extent of damage, synergistic impacts of anthropogenic and natural stressors, the health and resilience of reef building corals, and the communities' capacity for recovery (Smith *et al.* 2008). Ecological recovery and rapid restoration of normal reef processes has been documented in systems with intact functional groups and a high degree of spatial heterogeneity and connectivity (Nystrom *et al.* 2008), while degraded, overfished reefs fail to recover even after several decades of protection. During the Global Reef Expedition, research will emphasize

these four factors. The Foundation is targeting those nations that lack capacity and infrastructure to collect the scientific data they urgently need to fill knowledge gaps and contribute to new, ecosystem-based management approaches.

Operations

The Living Oceans Foundation (LOF) is a private operating, public benefit foundation based in Washington DC. LOF scientists and partners have conducted coral reef research over the last ten years with projects in the Pacific and Indian Oceans, the Red Sea, Mediterranean and Caribbean. The primary research platform is the Golden Shadow, a 67 m motor yacht that is graciously provided by HRH Prince Khaled bin Sultan of Saudi Arabia (Figure 1). The vessel carries multiple surface support vehicles, including a 38-foot dive boat, various tenders and the Golden Eye, a Cessna caravan float plane. The Golden Shadow has a stern elevator platform used to launch and recover the Golden Eye, as well as its various tenders, and can handle loads up to 12 tons. The platform is invaluable for diving access and recovery in difficult sea conditions. The Golden Shadow also contains a fully functional dive locker with a recompression chamber, a small laboratory outfitted with aquaria, an ocean chemistry system and other laboratory equipment, a Seakeepers weather and seawater monitoring system, and a satellite communication system.

Figure 1. Golden Shadow with one of our dive platforms, the Golden Osprey.

The Foundation relies on a core group of scientists from academic institutions worldwide for field activities, supplementing this with graduate students and Post Docs through our fellowship program, and partner with local and regional scientists, managers and stakeholders to implement the project. The GRE includes research, training for divers (Figure 2) and future scientists and managers, and education for communities, students, other local stakeholders, and the public about the importance of coral reefs and how they can contribute to their

preservation. The GRE began in April 2011 completing three missions in the Bahamas and one in St. Kitts and Nevis. Over the next five years, LOF will circumnavigate the globe to examine additional reefs in the Caribbean, followed by locations in the Pacific Ocean, Indian Ocean, and the Red Sea.

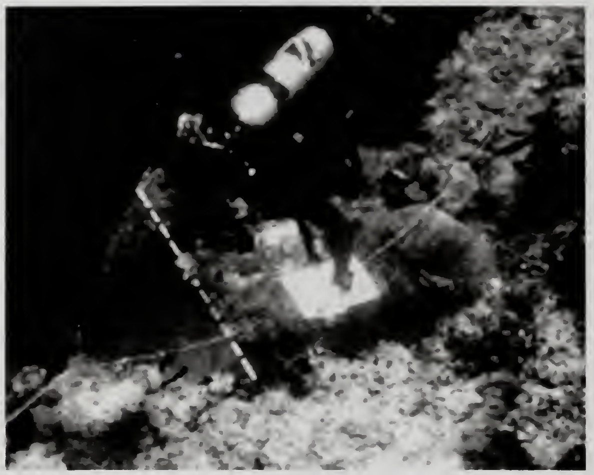

Figure 2. Diver measuring corals along a transect tape. The diver is holding a one meter bar and a slate.

Research Objectives

The long-term goal of the GRE is to increase scientific understanding of fundamental processes that shape coral reef ecosystems in the context of linkages and interactions at a "landscape" scale. High resolution mapping and habitat characterization underpin all Expedition studies and take advantage of the improvements made in recent years with multispectral satellite imagery. Using imagery collected by the new WorldView-2 satellite (DigitalGlobe Inc.) for key areas that are currently unmapped and identified as vital for conservation by resource management agencies in each country, these ecosystems are surveyed and ground-truthed using visual, photographic and acoustic sampling techniques. These data are incorporated into a Geographic Information System (GIS) database and are used to create high resolution habitat maps that depict the location, size, and distribution of various coral reef habitats, seagrass beds, mangroves, algal communities, sand flats, and other shallow marine habitats. Together, these tools form the basis for marine spatial management.

The LOF has also developed a standardized protocol to assess the health and resilience of reefs that allows comparison and ranking of reef

condition within individual locations, across geographic gradients, and between ocean basins. While typical monitoring programs provide data on cover of various organisms and the diversity and abundance of fishes, these often have limited taxonomic specificity (e.g., growth forms of corals are recorded instead of genera- or species-based data). Monitoring programs only rarely include an examination of the population dynamics of reef-building corals (e.g., size structure and amount of partial mortality) and fail to incorporate other parameters that allow an examination of relationships among coral, algae, and other functional groups.

The protocol LOF is applying during the GRE includes four major components: (1) an assessment of the primary biotic compartments that make up the reef community; (2) ecological interactions that drive dynamics within and among these groups; (3) habitat and environmental influences that directly affect the reefs; and (4) external drivers of change, including anthropogenic and climate factors. Representative sites are selected using high resolution multispectral satellite images and habitat maps, with sampling undertaken across gradients of human pressure and environmental regimes. Coral assessments focus on the diversity, benthic cover, size structure, extent of recent and old partial mortality, levels of recruitment, and condition of reef-building corals (Table 1a). Fish assessments include quantitative surveys of the abundance and size structure of more than 100 species of reef fishes, emphasizing species of major importance in the ecological functions of the reef ecosystem and fisheries targets, including key herbivores, piscivores, scavengers, coral feeders, sessile invertebrate feeders, planktivores, and detritivores (Table 1b). In addition to measures of substrate condition and cover and biomass of algae, more than 30 physical, environmental, and anthropogenic resilience indicators are also assessed (Table 1c).

In addition to the coral reef assessments, key ecological processes that shape these ecosystems – such as recruitment, herbivory, and bioerosion – are compared and contrasted across biophysical gradients and between geographic localities. An evaluation of specific parameters – such as diversity, productivity, habitat structure, anthropogenic stressors (fishing pressure), and various oceanographic parameters – is undertaken to determine their influence on ecological states of the reefs. For example, a number of different herbivore functional groups are recognized that mediate coral-algal dynamics, but each functional group contributes in a different manner, and their diversity, biomass and vulnerability to stresses (*e.g.* fishing) strongly affects how robustly each functional group

contributes to reef resilience. By assessing species assemblages of major herbivores, characterizing feeding patterns of different species and relationships between algal diversity and palatability by herbivorous fishes, and quantifying algal diversity and biomass, relative patterns of algal production, extent of herbivory, and risks of shifts towards macroalgal domination are assessed for each site. These data provide an indication of the consequences of fisheries that target herbivores and possible management measures to minimize impacts on reef health.

As LOF explores reefs around the world, representative sites in each country are established as Legacy Sites. These are similar to forest plots established by forestry biologists: large patches of reef that are permanently marked, digitally photographed to create high resolution mosaics illustrating each coral, sponge and other benthic organisms, and characterized in detail. By revisiting these sites every 2-5 years, it is possible to evaluate changes, such as the survival and growth of coral recruits and patterns of recovery from acute disturbances. These sites can also form a framework for future monitoring and will improve understanding of the fates of these systems under new management schemes and future climate change impacts.

Application of Findings to Management

Through research conducted during the GRE, LOF will acquire the knowledge and develop tools needed to assist resource managers in (1) implementing marine spatial planning with emphasis on development of marine protected areas, (2) promoting sustainable use of coral reef resources, and (3) preventing catastrophic declines of coral reefs and losses of ecosystem services that may be induced by large-scale global disturbances. The combined results of this work will contribute to a regional understanding of the current status of the coral reefs, and are intended to be used to predict future directions of reef health and categorize areas according to their level of threat and resilience. The knowledge gained through the GRE will help determine the role of individual species and community interactions in supporting fully functional reef ecosystems, and the environmental, biological, and physiological conditions that allow particular species to better survive under substandard conditions. It will also allow modeling and forecasting the key drivers of ecosystem health and components that can promote ecosystem recovery following periodic acute disturbances. By incorporating the information into landscape-scale management

approaches, the likelihood that reefs can persist under future scenarios of climate change can be greatly enhanced.

Today is like no other time in the past. Scientists know much more than ever before about coral reefs. The keystone species found here are known and the GRE will further clarify their importance in structuring these ecosystems. The major stressors have been identified, and their contribution to reef degradation will be further clarified through global assessments of reef health across geographical, biophysical, and anthropogenic gradients. Together with the resulting habitat maps, these data can help identify decisive actions that can be taken to mitigate these impacts. Through the GRE, LOF will fill knowledge gaps, share this information with the world in a timely manner, and provide technology and tools to resource managers that can aid in implementing the appropriate conservation and sustainable management approaches.

References

Aronson, R. B., I. G. MacIntyre, C. M. Wapnick, and M. W. O'Neill. 2004. Phase shifts, alternative states, and the unprecedented convergence of two reef systems. Ecology 85: 1876–1891.

Baker, A. C., P. W. Glynn, and B. Riegl. 2008. Climate change and coral reef bleaching: An ecological assessment of long-term impacts, recovery trends and future outlook. Estuarine, Coastal, and Shelf Science 80: 435–471.

Bellwood, D. R., and P. C. Wainwright. 2002. The history and biogeography of fishes on coral reefs. Pages 5–32 *in* P. F. Sale, editor. Coral reef fishes, dynamics and diversity in a complex ecosystem. Academic Press, San Diego, California.

Birkeland, C. 1997. Chapter 1: introduction. Pages 1–10 *in* C. E. Birkeland, editor. Life and death of coral reefs. Chapman and Hall, New York.

Choat, J. H., and D. R. Bellwood. 1991. Reef fishes: their history and evolution. Pages 39–66 *in* P. F. Sale, editor. Coral reef fishes, dynamics and diversity in a complex ecosystem. Academic Press, San Diego, California.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–260.

Harvell, D., E. Jordán -Dahlgren, S. Merkel, E. Rosenberg, L. J. Raymundo, G. Smith, E. Weil, and B. L. Willis. 2007. Coral disease, environmental drivers, and the balance between coral and microbial associates. Oceanography 20: 172–195.

Hobson, E. S. 1991. Trophic relationships of fishes specialized to feed on zooplankters above coral reefs. Pages 69–95 *in* P. F. Sale, editor. The ecology of fishes on coral reefs. Academic Press, San Diego, California.

Hughes, T. P. 1989. Community structure and diversity of coral reefs - the role of history. Ecology 70: 275–279.

Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265: 1547–1551.

Knowlton, N. 1992. Thresholds and multiple stable states in coral reef community dynamics. American Zoology 32: 674–682.

McClanahan, T.R., M. Ateweberhan, N. A. J. Graham, S. K. Wilson, C. R. Sebastian, M. M. M. Guillaume, and J. H. Bruggemann. 2007. Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. Marine Ecology Progress Series 337: 1–13.

Nystrom, N., N. A. J. Graham, J. Lokrantz, and A.V. Norstrom. 2008. Capturing the cornerstones of coral reef resilience: linking theory to practice. Coral Reefs 27: 795–809.

Rotjan, R. D. and S. M. Lewis. 2008. The impact of coral predators on tropical reefs. Marine Ecology Progress Series 367: 73–91.

Sale, P. F. 2002. Management of coral reef fishes. Pages 359–360 *in* P. F. Sale, editor. Coral reef fishes, dynamics and diversity in a complex ecosystem. Academic Press, San Diego, California.

Smith, L., J. Gilmour, and A. Heyward. 2008. Resilience of coral communities on an isolated system of reefs following catastrophic mass-bleaching. Coral Reefs 27: 197–205.

Spalding, M. D., C. Ravilious, and E. P. Green. 2001. *World atlas of coral reefs*. University of California Press, Berkeley, California.

Wilkinson, C. 2008. Status of Coral Reefs of the World: 2008. Townsville, Australia: Global Coral Reef Monitoring Network and Reef and Rainforest Research Center.

Table 1a. Resilience assessments for stony corals.

Measure	Description
Stony coral	Genus-level identification of the composition, abundance, cover, size structure, condition, and level of recruitment within representative habitats.
Species composition	The diversity and structural complexity of a site. Communities with higher numbers of functional groups (e.g. branching, plating, massive corals) and redundancy of these groups may support more associated species and be more resilient.
Cover	Measure of amount of living coral. Small changes in cover are difficult to document, but abrupt changes may reflect a major disturbance.
Size structure	Maturity and ecological state of the taxa. Dominance of large corals may be a sign of stable environmental conditions and long term persistence of the community; a dominance by small corals suggests frequent disturbance or recovery from a recent disturbance.
Recruitment	Abundance of recruits reflects the reef's potential for growth and recovery after major disturbances and the influx of genetic diversity.
Fragmentation	Level of physical disturbance and potential for asexual propagation. Locations of fragments (accumulations in sand channels or on reef) and fragment condition (no tissue loss; fusion to the substrate; presence of new growth) reflect the potential survival and contribution of fragments to recovery.
Dead standing coral	Amount of dead standing coral can be used to hindcast past disturbance events up to a decade or more.
Old mortality	Presence of dead areas on corals that are colonized by other biotic agents (*e.g.* skeleton is not white). Species specific differences reflect the life history strategies, population dynamics, and susceptibility to various physical and biological factors. Old mortality may increase with colony size.
Recent mortality	Extent of recent mortality (white skeleton) reflects the severity, timing and duration of a stressor. Large white areas indicate rapid ongoing tissue loss, while a thin band of white skeleton and wide band of green, algal colonized skeleton suggests the event is near its end.
Bleaching	Reef-wide bleaching may be associated with recent or ongoing temperature anomalies; extent of recent mortality in bleached corals indicates the duration and severity of the temperature stress.
Disease	Spatial patterns of disease reflect potential for spread and level of contagion. Distinction between background mortality (chronic stressors) and disease outbreaks (acute mortality).
Corallivores	Abundance of coral predators (*Drupella* and *Coralliophila* snails, *Acanthaster* seastars) indicative of the amount of recent mortality and possible changes to coral community structure and

		species diversity due to chronic high level infestations or outbreaks.
	Competition & overgrowth	Negative factors inhibiting the growth and recovery of corals and causes of chronic mortality (e.g. algal competition) and bioerosion (e.g. sponges). Extent and composition of competitor may reflect status of fish communities (herbivores), nutrient loading and sedimentation.
	Coral associates	Obligate corallivores (butterflyfish) provide an indication of the health of the coral community or a particular taxa.
		Abundance and diversity of fishes and invertebrates within coral branches are indicative of the topographic complexity and health of the site.
		An abundance of territorial damselfish within branches and large algal lawns indicate possible overfishing of piscivores.
		High densities of sea urchins may be associated with extensive bioerosion of reef substrates and low recruitment and survival of newly settled corals; macroalgae may increase in absence of sea urchins, especially sites with few herbivorous fishes.

Table 1b. Other bioindicators of resilience.

Measure		Description
Algae		Species rich, productive and functionally important components of benthic coral reef environments that may be involved in construction of the reef, components of the food chain, or space occupiers that are not eaten.
	Fleshy Macroalgae	Indicators of grazing pressure, nutrients and levels of disturbance. Macroalgae should be low in areas with low anthropogenic nutrients and runoff and high herbivory. Shifts toward macroalgal dominance reflect loss of key functional groups of herbivores (urchins/fish), nutrient input, and mass mortality of corals.
	Turf algae	Low to moderate cover of turfs reflect moderate levels of herbivory; increasing biomass of turfs and trapping of sediments within turfs may indicate poor substrate quality that reduces recruitment potential of reef-builders.
	Crustose coralline	Cover of certain species of crustose coralline algae is indicative of the suitability of substrate to support coral recruitment; CCAs bund sediments and consolidate the reef.
	Erect coralline	Taxa (*Halimeda*) produce sand that forms beaches and contribute to infilling of reefs.
Motile invertebrates		
	Urchins	Numbers of urchins (*Diadema* and *Echinometra*) are indicators of herbivory and bioerosion, survival of coral recruits, and interactions among other herbivores.
	Molluscs and crustaceans	Abundance of commercially important species such as large crabs, lobsters and giant clams are indicators of fishing pressure and habitat quality.

Fish	Fish community structure within sites can be attributed to environmental conditions, habitat complexity and quality, connectivity with other sites and intactness of adjacent habitats, and fishing pressure and management regimes.
HERBIVORES	Suppress the growth of algae. Herbivore biomass is negatively correlated with macroalgal biomass and amount of cropped habitat. Different functional groups prefer different taxa of algae and their impact to substrates and corals varies type and frequency of feeding.
Browsers	Feed on fronds of fleshy and filamentous macroalgae, controlling overgrowth and shading of corals by algae. Examples: *Calotomus, Leptoscarus, Naso.*
Grazers	Remove epilithic algae from reef surfaces without removal of underlying reef substrate. Examples: *Acanthurus, Zebrasoma, Siganus*.
Scrapers	Remove algae and small pieces of underlying reef substrate. Examples: *Scarus*.
Excavators	Consume coral and large pieces of reef substrate and play a key role in bioerosion and sand production. Examples: *Bolbometapon, Chlorurus*.
OMNIVORES	These species will consume small invertebrates including larvae, fish and fish larvae, and some consume phytoplankton, benthic algae and seagrass.
Detritivores	Feed on organic material in the sediment and on reef subtrates. High numbers may reflect conditions of eutrophication. Examples: goatfish, *Ctenochaetus*.
Planktivores	Indicative of the level of plankton in the water column, including larvae to reseed the reef; secondary indication of water column nutrient levels. Examples: fusiliers, some triggerfish.
CARNIVORES	Carnivore density, size and biomass is a sensitive indicator of the type of fishing pressure; these species are important in controlling abundances of lower trophic level fishes.
Invertivores	Control populations of corallivores and bioeroders (snails, sea stars and urchins). Also feed on sessile invertebrates like soft corals and sponges which compete with stony coral for space. Examples: triggerfish, snappers, sweetlips, wrasses, angelfish.
Obligate coral feeders	These species may provide indication of the health of the coral, especially species that are not generalists like certain butterflyfish.
Piscivores	Important control of lower trophic level fish; they are the first indicators of overfishing.

Table 1c. Physical and environmental resilience indicators.

Associated habitats		Proximity, connectivity and size of associated habitats, including grassbeds, mangroves, and algal flats are important in stabilizing sediments, reducing run-off to reef habitats, feeding grounds for reef-associated species, translocation of nutrients, habitat used during different life stages of reef species, and the provision of shelter for juvenile fishes and invertebrates.
Physical and environmental parameters		
	Tides	Large tides may reduce thermal stress and increase nutrients in subtidal areas; corals in areas exposed at low tide may be more resistant to high thermal stress, salinity and light.
	Currents	Likelihood of connectivity with other sites; helps maintain cooler water temperatures.
	Wave action	Affects distribution of species and growth form; enhance exchange of water and may maintain cooler temperatures.
	Deep water	Deep water adjacent to reefs may be associated with upwelling of cool, nutrient rich waters; pelagic fish that migrate and feed on reefs.
	Inter- reef distances	Potential for connectivity with adjacent sites.
	Distance from mainland	Gradient of anthropogenic stressors and exposure to open ocean conditions.
Reef attributes		
	Substrate type and quality	Reflects the potential for recruitment and survival of juvenile corals; measures include extent of sedimentation, turbidity, presence of rubble, smooth vs. rugose hardground.
	Reef slope	Proximity of deep water and potential for refuge populations; extensive shallow reef flats may heat up during calm periods and hot, hypersaline water may flow down the reef slope.
	Shading	Above water features and canopy corals that may shade understory corals, enhancing their hesitance to temperature-related stressors.
	Turbidity	Reduces penetration of UV, potentially reducing stress from thermal anomalies; may restrict vertical distribution of corals; turbidity due to resuspension vs anthropogenic run-off have different implications.
	Depth	Affects abiotic parameters (light, temperature, wave exposure), coral composition and growth form and habitats available for reef-associated fishes.
	Compass direction	Angle of incidence of the sun and diurnal changes affect amount of radiation the reef is exposed to; easterly facing reefs may exhibit more light stress than westerly facing reefs.

Exoplanets

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Abstract

Are there planets around other stars? This question finally has been answered in our lifetime. The answer is a very definite yes! However, most of the planets detected to date are large, Jupiter-mass or greater. The question we would really like to answer is: Are there Earth-like planets in a habitable zone around other stars? In other words, are we alone? That question is much more difficult to answer. But, we are making progress towards that goal. An extra-solar planet, or exoplanet, is a planet outside our Solar System. There are well over 500 candidate extra-solar planets identified as of May 6, 2011.

Introduction

The search for other planets and the search for other life are of long standing interest to humanity. "'Tis not probable we are the only fools in the universe," is a quote from *Entretiens sur la pluralité des mondes* by de Fontenelle in 1686. People often speculated on other life and planets.

The centuries-old quest for other worlds like our Earth has been rejuvenated by the intense excitement and popular interest surrounding the discovery of hundreds of planets orbiting other stars.

There is now clear evidence for substantial numbers of three types of exoplanets: gas giants, hot-super-Earths in short period orbits, and ice giants. The following website tracks the day-by-day increase in new discoveries and provides information on the characteristics of the planets as well as those of the stars they orbit: The Extra-solar Planets Encyclopedia at http://exoplanets.eu.

There are a few general questions we can address right away. Perhaps the first one is: what is a planet? Among other duties the International Astronomical Union (IAU) is the governing body for naming and defining astronomical objects as established by international treaty. The official definition of "planet" used by the IAU only covers the Solar System and thus takes no stance on exoplanets. As of April 2011, the only definitional statement issued by the IAU that pertains to exoplanets is a working definition issued in 2001 and modified in 2003. This definition contains the following criteria:

- Objects with true masses below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) that orbit stars or stellar remnants are "planets" (no matter how they formed). The minimum mass/size required for an extra-solar object to be considered a planet should be the same as that used in our Solar System.
- Substellar objects with true masses above the limiting mass for thermonuclear fusion of deuterium are "brown dwarfs," no matter how they formed or where they are located.
- Free-floating objects in young star clusters with masses below the limiting mass for thermonuclear fusion of deuterium are not "planets," but are "sub-brown dwarfs" (or whatever name is most appropriate).

The prose is a bit lawyer-like; however, basically a planet is a body that cannot fuse deuterium and has less mass than about 13 Jupiters.

Now that we have a working definition of a planet, another question is: do planets exist? We know of one example for sure – our own Solar System. So it certainly is possible. We also know, in general, how planets form:

- Stars form in collapsing molecular clouds. Disks of material appear to be a natural result of the cloud collapse. We can see these disks around young stars forming in our Galaxy.
- If these disks contain enough material (besides hydrogen and helium gas) then planets can form as the disk cools and condenses.

Finally then, what does our Solar System tell us about planetary systems in general?

- Planets orbit in the same plane as expected if they formed in a rotating disk.
- Planets (except Mercury) have almost circular orbits.
- Small rocky planets form near the Sun (or central star); gas giants far from the Sun. We explain this by temperature: near the Sun it was too warm for water to condense; far from the Sun water ice was stable, adding to the material available to form planets – and gas molecules were moving more slowly allowing the growing planets to trap large amounts of hydrogen and helium gas from the disk.

Since these characteristics are consistent with planet formation from a circum-stellar disk, we would expect other planetary systems to be similar to our own.

Early History of Planet Searches

Astrometry is the oldest search method for extra-solar planets. Astrometry is the precise measurement of stellar positions and motions and is the most fundamental aspect of astronomical work. The search method dates back at least to statements made by William Herschel in the late 18th century. He claimed that an unseen companion was affecting the position of the star he cataloged as 70 Ophiuchi (star number 70 in the constellation of Ophiuchus).

The first known formal astrometric calculation for an extrasolar planet was made by Captain W. S. Jacob in 1855 at the East India Company's Madras Observatory. He reported that orbital anomalies made it "highly probable" that there was a "planetary body" in the 70 Ophiuchi system.[i] In the 1890s Thomas J. J. See of the University of Chicago and the United States Naval Observatory stated that the orbital anomalies proved the existence of a dark body in the 70 Ophiuchi system with a 36-year period around one of the stars.[ii] However, Forest Ray Moulton (probably around 1915) proved that a three-body system with those orbital parameters would be highly unstable. During the 1950s and 1960s, Peter van de Kamp of Swarthmore College made another series of detection claims, this time for planets orbiting Barnard's Star.[iii]

Astronomers now generally regard all the early reports of detection as erroneous. For two centuries claims had circulated of the discovery of unseen companions in orbit around nearby star systems that all were reportedly found using this method, culminating in the 1996 announcement of multiple planets orbiting the nearby star Lalande 21185 by astronomer George Gatewood. None of these claims survived scrutiny by other astronomers, and the astrometric technique fell into disrepute. All claims of a planetary companion of less than 0.1 solar mass made before 1996 using this method are likely spurious.

In 2002, astronomers did succeed in using astrometry to characterize a previously discovered planet around the star Gliese 876 (star number 876 in the Gliese catalog of stars).

One potential advantage of the astrometric method is that it is most sensitive to planets with large orbits. This makes it complementary to other methods that are most sensitive to planets with small orbits.

However, very long observation times are required — years, and possibly decades, as planets far enough from their star to allow detection via astrometry also take a long time to complete an orbit.

The first published, confirmed discovery of an exoplanet was made in 1988 by the Canadian astronomers Bruce Campbell, G. A. H. Walker, and S. Yang.[iv] Although they were cautious about claiming a planetary detection, their radial-velocity observations (see below for a description of this technique) suggested that a planet orbited the star Gamma Cephei. Partly because the observations were at the very limits of instrumental capabilities at the time, widespread skepticism persisted in the astronomical community for several years about this and other similar observations. Another source of confusion was that some of the possible planets might instead have been brown dwarfs, objects that are intermediate in mass between planets and stars. The following year, however, additional observations were published that supported the reality of the planet orbiting Gamma Cephei, though subsequent work in 1992 raised serious doubts. Finally, in 2002, improved techniques allowed the planet's existence to be confirmed.

Another early detection was in 1992, with the discovery of two confirmed terrestrial-mass planets orbiting the pulsar PSR B1257+12. The first confirmed detection of an exoplanet orbiting a main-sequence star was made in 1995, when a giant planet, 51 Pegasi b, was found in a four-day orbit around the nearby G-type star 51 Pegasi. The frequency of planet detections has increased since then.

Why Can't We See Planets The Way We Can See Mars?

Any planet is an extremely faint light source compared to its parent star. In addition to the intrinsic difficulty of detecting such a faint light source, the light from the parent star causes a glare that washes it out. As viewed from a distant star, the Sun is 600,000,000 times as bright as Jupiter, 2.5 billion times as bright as Saturn, and 25 billion times as bright as Earth.

Planets are also distant. Because of the great distances to the stars, the small angular separation between a star and its planet is difficult to resolve.

For these reasons, a planet would be lost in the glare of its host star. Only a very few exoplanets have been observed directly.

Instead, astronomers generally had to resort to indirect methods to detect extra-solar planets. At the present time, several different indirect methods have yielded success.

Indirect Methods of Detection

There are four main indirect methods, the first two are the primary ones: (1) Detecting Planets by Radial Velocity Searches; (2) Detecting Planets via Transits, (3) Detecting Planets through Gravitational Microlensing; (4) Detecting Planets through Timing.

Detecting Planets by Radial Velocity Searches

From Newton's laws we know that the gravitational pull is mutual; a planet pulls on its star just as the star pulls on the planet. Thus, the two objects will orbit around their common center of mass; while the planet executes one orbit around the star, the much more massive star executes a small wobble as well. For example, Jupiter's gravitational pull causes the Sun to wobble at a speed of about 12 meters/sec. We can detect the motion of the star pulled by an unseen planet via the Doppler shift of the star's spectral lines; *i.e.*, the tiny variations in the radial velocity of the star with respect to Earth.

Radial velocity is the velocity of an object in the direction of the line of sight (*i.e.* its speed straight towards or away from an observer). In astronomy, radial velocity most commonly refers to the spectroscopic radial velocity. The spectroscopic radial velocity is the radial component of the velocity along the line-of-sight between the emitter and the observer, so the frequency of the light decreases for sources that are receding (redshift) and increases for sources that are approaching (blueshift) – the Doppler shift. Astrometric radial velocity is the radial velocity as determined by astrometric observations (for example, a secular change in the annual parallax).

The Doppler shift of a spectral line depends on the ratio of the object's velocity to the speed of light. One determines the velocity, v, by measuring the wavelength shift ($\Delta\lambda$) from the central wavelength λ:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}.$$

Radial velocity can be used to estimate the masses of the binary systems and some orbital elements, such as eccentricity and semi-major axis. The same method is also used to detect planets around stars, in the

way that the radial velocity variation determines the planet's orbital period, while the resulting size of the displacement allows the calculation of the lower bound on a planet's mass. Radial velocity methods alone may only reveal a lower bound, since a large planet orbiting at a very high angle to the line of sight will perturb its star radially as much as a smaller planet with an orbital plane on the line of sight. It has been suggested that planets with high eccentricities calculated by this method may be mimicking two planet systems of circular or near-circular resonant orbit.

The graph in Figure 1 illustrates the sine curve created using Doppler spectroscopy to observe the radial velocity of an imaginary star which is being orbited by a planet in a circular orbit. Each dot is a measurement of the position of the star's spectral line (as shifted from its central position). Observations of a real star will produce a similar graph, although eccentricity in the orbit will distort the curve. When v_{star} is the velocity of parent star, the observed Doppler velocity is $K = v_{star} \sin(i)$, where i is the inclination of the planet's orbit to the line perpendicular to the line-of-sight.

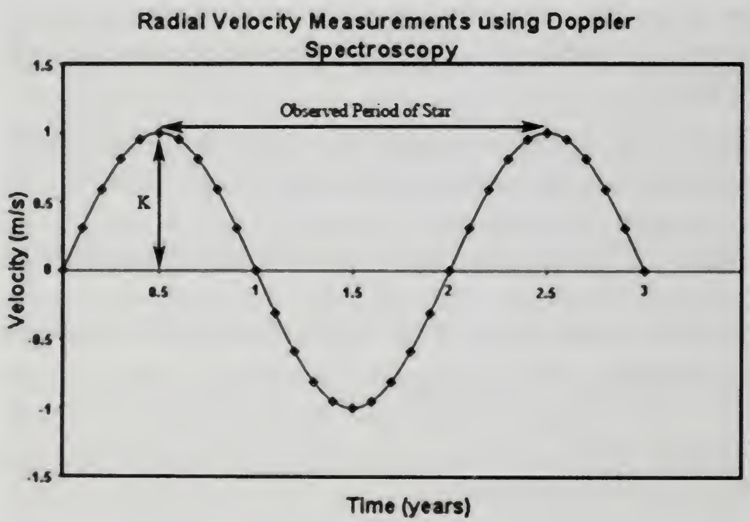

Figure 1. The Doppler shift of an imaginary star

To observe such a small Doppler shift, a very special accurate spectrograph is required, as well as a sophisticated computer analysis. An Olympic sprinter runs the 100-meter dash in 10 seconds, or 10 m/sec. You or I could run at 3 m/sec (briefly!). And that's the sensitivity of these specialized spectrometers.

A team led by astronomers Geoff Marcy and Paul Butler developed such an instrument. In 1995, they put their instrument on the Keck 10-

meter telescope and began systematic observations of several hundred stars, expecting to accumulate years of data to detect planets on orbits like Jupiter. Well, within a year, the first planet detection was announced – a planet with a 4-day period. Soon, a number of Jupiter-mass planets on very short orbits were discovered.

The velocity of the star around the center of mass is much smaller than that of the planet, because the radius of its orbit around the center of mass is so small. Velocity variations down to 1 m/s can be detected with modern spectrometers, such as the HARPS (High Accuracy Radial Velocity Planet Searcher) spectrometer at the 3.6 meter telescope in La Silla Observatory, Chile, or the HIRES (High Resolution) spectrometer at the Keck telescopes in Hawaii.

The major problem with Doppler spectroscopy is that it can only measure movement along the line-of-sight, and so depends on a measurement (or estimate) of the inclination of the planet's orbit to determine the planet's mass. If the orbital plane of the planet happens to line up with the line-of-sight of the observer, then the measured variation in the star's radial velocity is the true value. However, if the orbital plane is tilted away from the line-of-sight, then the true effect of the planet on the motion of the star will be greater than the measured variation in the star's radial velocity, which is only the component along the line-of-sight. As a result, the planet's true mass will be higher than expected. We do not know the orientation of the orbit: how much it is tilted to our line of sight. Since we can only measure the motion towards or away from us, we do not necessarily measure the full velocity of the star.

To correct for this effect, and so determine the true mass of an extra-solar planet, radial velocity measurements must be combined with astrometric observations, which track the movement of the star across the plane of the sky, perpendicular to the line-of-sight. Astrometric measurements allow researchers to check whether objects that appear to be high mass planets are more likely to be brown dwarfs.

The radial velocity method has certain selection effects: it is easier to detect more massive objects and easier to detect objects on close-in orbits. So, we don't yet know whether smaller, Earth-like planets are common. Also, the unknown tilt of the orbit plane means that the 'planet' mass is a lower limit.

A further problem is that the gas envelope around certain types of stars can expand and contract, so these stars are variable. This method is

unsuitable for finding planets around these types of stars, as changes in the stellar emission spectrum caused by the intrinsic variability of the star can swamp the small effect caused by a planet.

The radial velocity method is best at detecting very massive objects close to the parent star — so-called "hot Jupiters" – which have the greatest gravitational effect on the parent star, and so cause the largest changes in its radial velocity. Observation of many separate spectral lines and many orbital periods allows the signal to noise ratio of observations to increase, thus increasing the chance of observing smaller and more distant planets; planets like the Earth remain undetectable with current instruments.

This has been a very productive technique used by planet hunters. The method is distance independent, but requires high signal-to-noise ratios to achieve high precision, and so is generally only used for relatively nearby stars out to about 160 light-years from Earth. It easily finds massive planets that are close to stars, but detection of those orbiting at great distances requires many years of observation. Planets with orbits highly inclined to the line of sight from Earth produce smaller wobbles, and are thus more difficult to detect. One of the main disadvantages of the radial-velocity method is that it can only estimate a planet's minimum mass. The posterior distribution of the inclination angle depends on the true mass distribution of the planets. The radial-velocity method can be used to confirm findings made by using the transit method (see the section on this). When both methods are used in combination, then the planet's true mass can be estimated.

Results of Radial Velocity Searches So Far

Two groups (Marcy *et al.* at Berkeley; Mayor *et al.* at Geneva) have now been searching for planets with this technique for almost 15 years. They use special spectrometers with very stable platforms and calibration combined with the largest optical telescopes on Earth. The limiting velocity sensitivity is now down to just 1.5 meters/sec!

At least 50 stars have been found to have multiple planets. Because the detection of multiple periodicities in the radial velocity curve requires many more data points, the number of multiple planet systems is likely to increase as the research teams acquire more data.

The exoplanets detected by this technique (> 520 objects as of 3/2011) have characteristics very different from our solar system:

1. Large gas giants are found very close to the central star.
2. Most of the detected planets have large masses, comparable to the mass of Jupiter; many are larger than Jupiter.
3. Many planets are on very elliptical orbits (about half of the sample).

One method for detecting smaller planets is to observe stars less massive than the Sun. Stars with mass 0.5 to 0.3 that of the Sun are quite common. They are fainter – and not as hot – as the Sun, but could still have a habitable zone 0.1 – 0.2 AU from the star.

In the past three years, 12 planets have been detected with masses of 2 to 15 times the mass of Earth, small enough that these may be rocky planets. (Jupiter's mass is 318 × Earth's mass). Two of them orbit within the potential habitable zone around one of these fainter stars:

One recent example: 4 planets around the small red star GJ581[v]

Mass of planet (Earth masses)	Distance from Star
1.94	0.03 AU – least massive planet yet detected!
15.6	0.04 AU
5.0	0.07 AU inner edge of habitable zone?
7.7	0.25 AU habitable zone?

Could it be that these faint red stars have habitable planets? As of 2010 two more candidate exoplanets were discovered around GJ581.

Detecting Planets via Transits

When a planetary-sized object crosses in front of a star, we call it a transit (since only a small percentage of the light is blocked, it's not really an eclipse). We see occasional transits of Venus or Mercury here in our Solar System. So, another method of detecting a planet is to search for a small decrease in the amount of light from a star when a planet crosses in front of it. Of course, only a small fraction of the planetary systems will be oriented so that a planet crosses in front of a star as seen from Earth.

From ground-based telescopes, quite a few transiting planets have been detected. The decrease in the amount of light from the star during a transit is about 0.5% – 2%, corresponding to a fairly large planet. See Figure 2. From the percentage decrease and the duration of the brightness decrease, we can determine the size of the planet:

- The drop in brightness during the transit tells us the fractional area of the star that is blocked by the transiting planet.
- If we know the true cross-section area of the star (from stellar models, compared to the Sun), then we can determine the cross-section area of the planet, and thus its diameter.

When combined with radial velocity measurements to determine the mass of the planet, we can then calculate the density of the planet, a real physical quantity that tells us something about the nature of the object (gas giant versus rocky planet).

While the other methods provide information about a planet's mass, this photometric method can determine the radius of a planet. If a planet crosses (transits) in front of its parent star's disk, then the observed visual brightness of the star drops a small amount. The amount the star dims depends on the relative sizes of the star and the planet. For example, in the case of HD 209458, the star dims 1.7%.

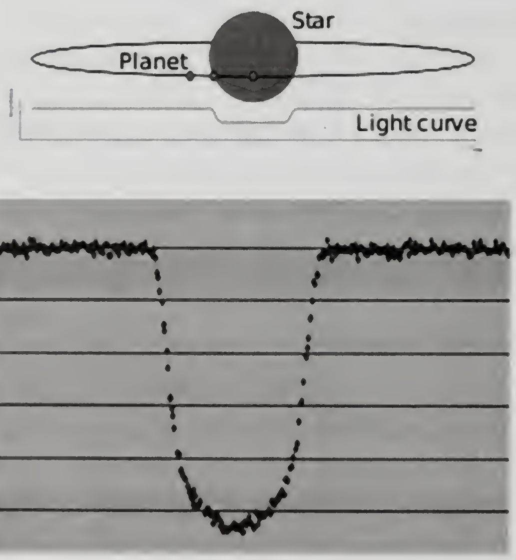

Figure 2. Example of the transit method. The bottom figure shows the dip in light as the planet passes in front of the star.

The main advantage of the transit method is that the size of the planet can be determined from the light curve. When combined with the radial velocity method (which determines the planet's mass) one can determine the density of the planet, and hence learn something about the planet's

physical structure. The nine planets that have been studied by both methods are by far the best-characterized of all known exoplanets.

The transit method also makes it possible to study the atmosphere of the transiting planet. When the planet transits the star, light from the star passes through the upper atmosphere of the planet. By studying the high-resolution stellar spectrum carefully, one can detect elements present in the planet's atmosphere. A planetary atmosphere (and planet for that matter) could also be detected by measuring the polarization of the starlight as it passed through or is reflected off the planet's atmosphere.

This method has two major disadvantages. First, planetary transits are only observable for planets whose orbits happen to be perfectly aligned from the astronomers' vantage point. The probability of a planetary orbital plane being directly on the line-of-sight to a star is the ratio of the diameter of the star to the diameter of the orbit. About 10% of planets with small orbits have such alignment, and the fraction decreases for planets with larger orbits. For a planet orbiting a sun-sized star at 1 AU, the probability of a random alignment producing a transit is 0.47%. However, by scanning large areas of the sky containing thousands or even hundreds of thousands of stars at once, transit surveys can in principle find extra-solar planets at a rate that could potentially exceed that of the radial-velocity method, although it would not answer the question of whether any particular star is host to planets.

Second, the method suffers from a high rate of false detections. A transit detection requires additional confirmation, typically from the radial-velocity method.

The secondary eclipse (when the planet is blocked by its star) allows direct measurement of the planet's radiation. If the star's photometric intensity during the secondary eclipse is subtracted from its intensity before or after, only the signal caused by the planet remains. It is then possible to measure the planet's temperature and even to detect possible signs of cloud formations on it. In March 2005, two groups of scientists carried out measurements using this technique with the Spitzer Space Telescope. The two teams, from the Harvard-Smithsonian Center for Astrophysics, led by David Charbonneau, and the Goddard Space Flight Center, led by L. D. Deming, studied the planets TrES-1 and HD 209458b respectively. The measurements revealed the planets' temperatures: 1,060 K (790°C) for TrES-1 and about 1,130 K (860°C) for HD 209458b. However some transiting planets orbit such that they do not enter secondary eclipse relative to Earth.

The CoRoT mission, developed primarily by the French Space Agency, was the first space mission dedicated to observing transits. It has been in orbit around Earth for over 4 years and can reliably detect brightness changes of 0.1%. The 17^{th} CoRoT exoplanet was announced in 2010.

Detecting Planets through Gravitational Microlensing

Gravitational microlensing occurs when the gravitational field of a star acts like a lens, magnifying the light of a distant background star. This effect occurs only when the two stars are almost exactly aligned. Lensing events are brief, lasting for weeks or days, as the two stars and Earth are all moving relative to each other. More than a thousand such events have been observed over the past ten years. See Figure 3 for an illustration.

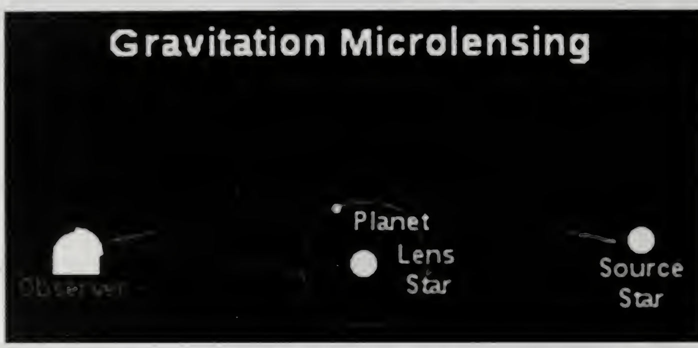

Figure 3. Illustration of the microlensing search for a planet

If the foreground lensing star has a planet, then that planet's own gravitational field can make a detectable contribution to the lensing effect. Since that requires a highly improbable alignment, a very large number of distant stars must be continuously monitored in order to detect planetary microlensing contributions at a reasonable rate. This method is most fruitful for planets between Earth and the center of the Galaxy, as the Galactic center provides a large number of background stars.

In 1991, astronomers Shude Mao and Bohdan Paczyński of Princeton University first proposed using gravitational microlensing to look for exoplanets. Successes with the method date back to 2002, when a group of Polish astronomers (Ansezej Udalski, Marcin Kubiak and Michał Szymański from Warsaw, and Bohdan Paczyński) during project OGLE (the Optical Gravitational Lensing Experiment) developed a workable technique. During one month they found several possible planets, though limitations in the observations prevented clear confirmation. Since then,

four confirmed extrasolar planets have been detected using microlensing. As of 2006 this was the only method capable of detecting planets of Earthlike mass around ordinary main-sequence stars.

A notable disadvantage of the method is that the lensing cannot be repeated because the chance alignment never occurs again. Also, the detected planets will tend to be several kiloparsecs away, so follow-up observations with other methods are usually impossible. However, if enough background stars can be observed with enough accuracy then the method should eventually reveal how common Earthlike planets are in the Galaxy.

On May 18, 2011 astronomers announced the discovery of a new class of Jupiter-sized planets floating alone in the dark of space, away from the light of a star. The team believes these lone worlds are probably outcasts from developing planetary systems and, moreover, they could be twice as numerous as the stars themselves. These are free-floating planets.

The discovery is based on a joint Japan-New Zealand microlensing survey that scanned the center of the Milky Way during 2006 and 2007, revealing evidence for up to 10 free-floating planets roughly the mass of Jupiter. The isolated orbs, also known as orphan planets, are difficult to spot, and had gone undetected until now. The planets are located at an average approximate distance of 10,000 to 20,000 light years from Earth.

The survey, the Microlensing Observations in Astrophysics (MOA), is named in part after a giant wingless, extinct bird family from New Zealand called the moa. A 5.9-foot (1.8-meter) telescope at Mount John University Observatory in New Zealand is used to regularly scan the copious stars at the center of our Galaxy for gravitational microlensing events.

This could be just the tip of the iceberg. The team estimates there are about twice as many free-floating Jupiter-mass planets as stars. In addition, these worlds are thought to be at least as common as planets that orbit stars. This adds up to hundreds of billions of lone planets in our Milky Way alone. The team sampled a portion of the Galaxy, and based on these data, can estimate overall numbers in the Galaxy.

The study, led by Takahiro Sumi from Osaka University in Japan, appears in the May 19 (2011) issue of the journal *Nature*. The survey is not sensitive to planets smaller than Jupiter and Saturn, but theories suggest lower-mass planets like Earth should be ejected from their stars

more often. As a result, they are thought to be more common than free-floating Jupiters.

Detecting Planets through Timing

When a double star system is aligned such that – from the Earth's point of view – the stars pass in front of each other in their orbits, the system is called an eclipsing binary star system. The time of minimum light, when the star with the brighter surface area is at least partially obscured by the disc of the other star, is called the primary eclipse, and approximately half an orbit later, the secondary eclipse occurs when the brighter surface area star obscures some portion of the other star. These times of minimum light, or central eclipse, constitute a time stamp on the system, much like the pulses from a pulsar (except that rather than a flash, they are a dip in the brightness). If there is a planet in circum-binary orbit around the binary stars, the stars will be offset around a binary-planet center of mass. As the stars in the binary are displaced by the planet back and forth, the times of the eclipse minima will vary; they will be too late, on time, too early, on time, too late, *etc*. The periodicity of this offset may be the most reliable way to detect extra-solar planets around close binary systems.

Direct Imaging

As mentioned previously, planets are extremely faint light sources compared to stars and what little light comes from them tends to be lost in the glare from their parent star. So in general, it is very difficult to detect them directly.

Ultimately, the goal is to image planets around other stars directly and to wring all the information possible out of those photons (planet temperature from infrared and atmospheric composition from infrared and visible light spectra).

The first direct detection was a single pixel in an image using an opaque disk within the camera (called a coronograph) to block the star's light and allow a long exposure image. This was planet Fomalhaut b, around the bright star Fomalhaut[vi]. The method used a series of selections:

- Observe a star that is larger, hotter, and more massive than the Sun. Thus the planet forming disk of material was presumably larger and more massive, and the habitable zone farther from the

star. An orbiting planet may be farther from the star, making it easier to detect.

- Observe at near-infrared wavelength where the brightness contrast between star and planet is not quite so extreme.
- Select a young star, where a larger planet has not lost all of its initial heating and will be brighter in the infrared.

They acquired images of Fomalhaut with space-based and ground-based telescopes, using an opaque disk in the camera to block the light from Fomalhaut. Images taken two years apart consistently show a faint dot that has moved slightly, consistent with the orbital velocity expected at that distance from Fomalhaut. The planet is about 119 AU from the star. Since the luminosity of Fomalhaut is 16 times that of the Sun, the planet would receive illumination from the star comparable to Neptune in our solar system.

Some projects to equip ground based telescopes with planet-imaging-capable instruments include: Gemini telescope (GPI), the Very Large Telescope (SPHERE), and the Subaru telescope (HiCIAO).

In July 2004, a group of astronomers used the European Southern Observatory's Very Large Telescope array in Chile to produce an image of 2M1207b, a companion to the brown dwarf 2M1207. In December 2005, the planetary status of the companion was confirmed. The planet is believed to be several times more massive than Jupiter and to have an orbital radius greater than 40 AU.

Up until the year 2010, telescopes could only directly image exoplanets under exceptional circumstances. Specifically, it is easier to obtain images when the planet is especially large (considerably larger than Jupiter), widely separated from its parent star, and hot so that it emits intense infrared radiation. However in 2010 a team from NASA's Jet Propulsion Laboratory demonstrated that a vortex coronagraph could enable small scopes to directly image planets. They did this by imaging the previously imaged HR 8799 planets using just a 1.5 m portion of the Hale Telescope. See Figure 4. The planet masses are 10, 10, and 7 times of Jupiter.

Images taken in 2003 and reanalyzed in 2008 revealed a planet orbiting Beta Pictoris which in 2009 was observed to have moved to the other side of the star. See Figure 5.

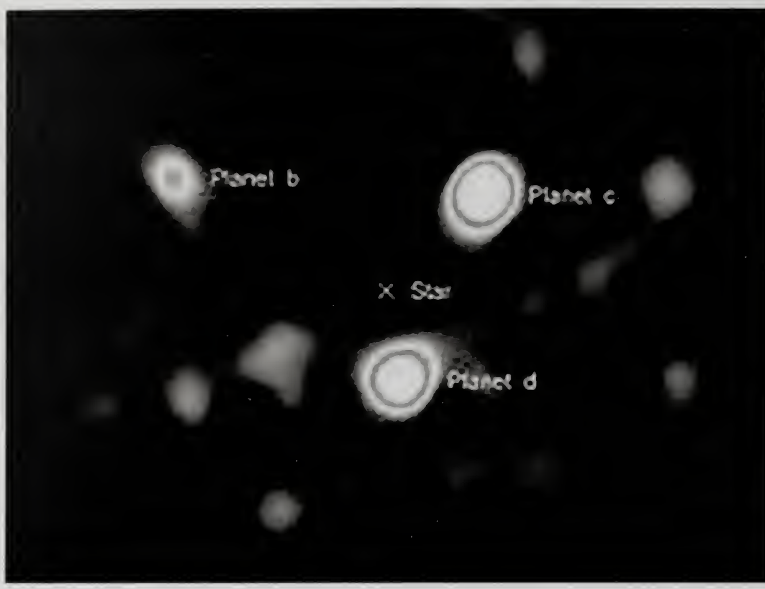

Figure 4. Direct image of exoplanets around the star HR8799 using a vortex coronagraph on a 1.5m portion of the Hale telescope.

Figure 5. ESO image of a planet near Beta Pictoris. The planet is the bright spot about 11 o'clock near the center of the image. The dotted circle (upper right) is the size of the orbit of Saturn scaled to this star.

In September 2008, an object was imaged at a separation of 330AU from the star 1RXS J160929.1−210524, but it was not until 2010 that it was confirmed to be a companion planet to the star and not just a chance alignment. An additional system, GJ 758, was imaged in November 2009, by a team using the HiCIAO instrument of the Subaru Telescope.

The Kepler Mission

The challenge now is to find terrestrial planets (*i.e.*, those one half to twice the size of the Earth), especially those in the habitable zone of their stars where liquid water and possibly life might exist. As of September 2010, Gliese 581 g, fourth planet of the red dwarf star Gliese 581, is the strongest possibly terrestrial exoplanet orbiting in the habitable zone surrounding its star, although the existence of Gliese 581 g has been questioned by another team of astronomers, and it is now listed as unconfirmed at The Extra-solar Planets Encyclopaedia.

Named for Johannes Kepler, the Kepler Mission was launched March 6, 2009 riding aboard a Delta II rocket. The Kepler spacecraft watches a patch of space for indications of Earth-sized planets moving around stars similar to the Sun. There are over 100,000 stars like the Sun in the area. Using special detectors similar to those used in digital cameras, Kepler will look for a slight dimming in the stars as planets pass between the stars and Kepler – the transit method. The observatory's place in space will allow it to watch the same stars constantly throughout its multi-year mission. It is a job only a computer could love.

Figure 6 shows the field of view of the Kepler instrument. It points between the constellations of Cygnus and Lyra at a dense field of stars. Data from the Kepler mission have been used to estimate that there are at least 50 billion planets in our own Galaxy.

Kepler is sensitive enough to detect planets even smaller than Earth. By scanning a hundred thousand stars simultaneously, it will not only be able to detect Earth-sized planets, it will be able to collect statistics on the numbers of such planets around sun-like stars.

The goal is to find Earth-like planets by searching for transits that cause a brightness decrease of just 1/10,000 with a periodicity of about 1 year – such detections will require all four years of data, in order to record repeated transits with a constant period.

Figure 6. Field of view of Kepler

As of February 2011, Kepler had identified 1,235 unconfirmed planetary candidates associated with 997 host stars, based on the first four months of data from the space-based telescope, including 54 that may be in the habitable zone. Six candidates in this zone were thought to be smaller than twice the size of Earth, though a more recent study found that one of the candidates is likely much larger and hotter than first reported.

- 68 planets with radii < 1.25 Earth radii
- 288 planets with radii between 1.25 and 2 Earth radii
- 662 planets with radii between 2 and 6 Earth radii (Neptune-sized)
- 165 Jupiter-sized planets with radii between 6 and 15 Earth radii
    - (Jupiter's radius is 11 Earth radii)
- 19 objects larger than 2 Jupiter radii

About 75% of these planets are smaller than Neptune (4 Earth radii). So far, 408 of the planets are in multiple-planet systems. And these results are just from 4 months of data, so only short-period close-in orbiting planets are included. These are called 'candidate' planets because follow-up observations are not yet available.

The Kepler dataset is so massive that astronomers are studying other things with the dataset. An international team of astroseismologists, led by the University of Birmingham, has used data from the NASA Kepler Mission to sample the 'stellar music' of 500 stars similar to the Sun.

according to research published 8 April 2011 in the journal *Science*. The team used the information from these natural resonances, which is coded in pulses of starlight, to measure the properties of these stars and will now be able to compare their findings with predictions based on models of the Milky Way.

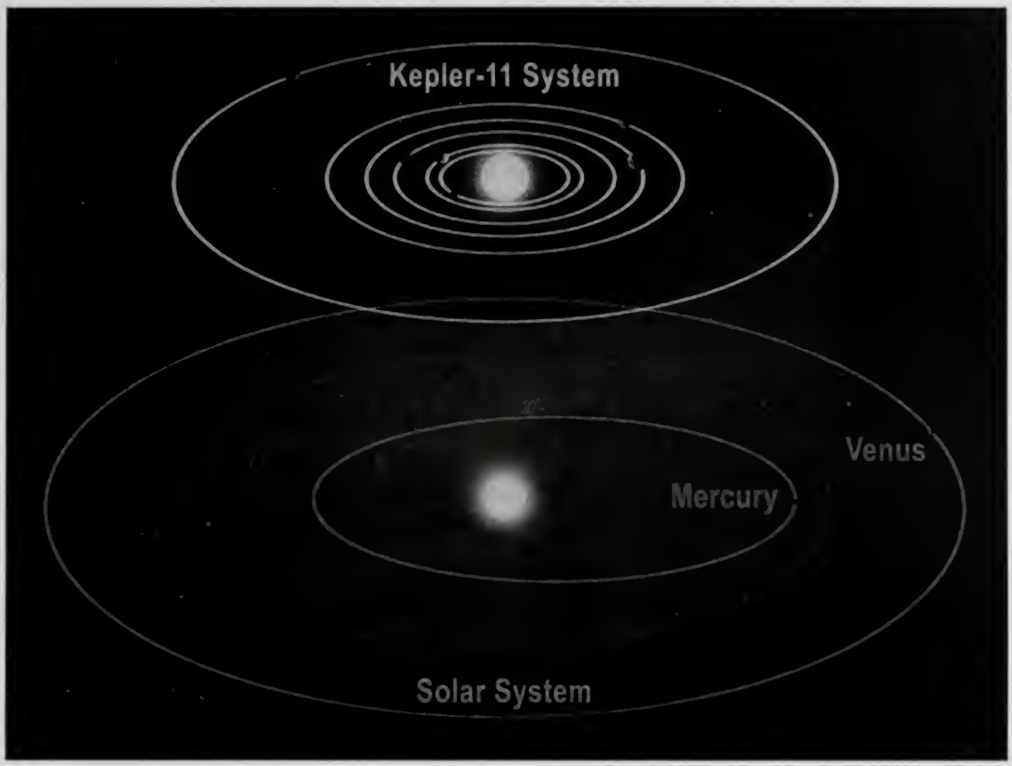

Figure 7. Artist's conception of Kepler 11.

Figure 7 is an artist's conception of the Kepler 11 solar system compared to our own. It shows the Kepler-11 planetary system and our solar system from a tilted perspective to demonstrate that the orbits of each lie on similar planes. Kepler 11 has the fullest, most compact planetary system yet discovered beyond our own. All six planets orbiting Kepler 11 are larger than Earth, with the largest ones being comparable in size to Uranus and Neptune. If placed in our solar system, the outermost planet would orbit between Mercury and Venus, and the other five planets would orbit between Mercury and our sun. The innermost planet, Kepler 11b, is ten times closer to its star than Earth is to the Sun.

Summing It Up

exoplanets.eu (May 2011)

Planetary candidates detected by radial velocity or astrometry

419 planetary systems
500 planets
50 multiple planet systems

Planetary candidates detected by transits

121 planetary systems
128 planets
10 multiple planet systems

1,235 candidates from Kepler, 16 confirmed

Planetary candidates detected by microlensing

11 planetary systems
12 planets
1 multiple planet systems

Planetary candidates detected by direct imaging

21 planetary systems
24 planets
1 multiple planet systems

Planetary candidates detected by timing

7 planetary systems
12 planets
4 multiple planet systems

After detecting hundreds of exoplanets in the 15 years up thru 2010, we are on the exciting threshold of detecting thousands of exoplanets and identifying Earthlike candidates. Perhaps someday soon we will know if there is life out there.

[i] Jacob, W.S. (1855). "On Certain Anomalies presented by the Binary Star 70 Ophiuchi." *Monthly Notices of the Royal Astronomical Society*, **15**, 228.

[ii] See, T. J. J. (1896). "Researches on the Orbit of 70 Ophiuchi, and on a Periodic Perturbation in the Motion of the System Arising from the Action of an Unseen Body." *The Astronomical Journal*, **16**, 17.

[iii] van de Kamp, P. (1969). "Alternate dynamical analysis of Barnard's star." *Astronomical Journal*, **74**, 757.

[iv] Campbell, B.; Walker, G. A. H.; Yang, S. (15 August 1988). "A search for substellar companions to solar-type stars." *Astrophysical Journal*, **331**, 902.

[v] Mayor, M. *et al.* (2009). "The HARPS search for southern extra-solar planets XVIII: An Earth-mass planet in the GJ 581 planetary system". *Astronomy and Astrophysics*, **507**, 487.

[vi] Kalas, P. *et al.* (2009). "Fomalhaut b: Direct Detection of a ε Jupiter-mass Object Orbiting Fomalhaut." *Bull. Amer. Astron. Soc.*, **41**, 491.

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Innovations in STEM Education

Sylvia M. James and Cora B. Marrett

National Science Foundation

Abstract

Recent changes in the K-12 career and technical education (CTE) sector suggest that the effective strategies utilized in this context may also be of interest to those concerned about science, technology, engineering and mathematics (STEM) education in the United States. Today's comprehensive CTE programs incorporate cutting edge technologies, sustainable practices, and workforce preparation in collaboration with local business and industry, often while also preparing students for postsecondary study. Concurrently, it has become apparent that preparing students for the future STEM workforce requires the utilization of all of the educational and community resources at our disposal, and increasingly educators and policymakers are looking to the informal sector. High quality, STEM enrichment programs offered outside of the classroom setting may provide authentic learning experiences and increase interest and engagement in STEM and related careers, especially among diverse populations. However, the link between CTE and informal science education remains relatively unexplored. Systematic study of career and technical secondary schools could strengthen our understanding of the various paths through which successful STEM education might be achieved. Additionally, closer examination of seemingly common goals in informal science education programs for youth may offer additional tools to prepare students for a world in which STEM knowledge and skills are valuable and necessary assets.

Innovations in STEM Education

The educational system in the United States has come under increasing scrutiny as school districts grapple with the challenge of preparing students for citizenry in an increasingly complex and technologically advanced global economy. Policymakers enact legislation that attempts to provide the tools for ensuring that high quality education is available to all students. National and common core standards aim to provide consistency and continuity in student knowledge and understanding of foundational concepts. Leaders from business and industry collaborate with academia to identify twenty-first century skills, taking actions often with the same

enthusiasm evident in a report from the 1990s from the U.S. Department of Labor: the Secretary's Commission on Achieving Necessary Skills.[i]

Perhaps the quality education the U.S. seeks can be achieved through a broad range of innovative strategies. This article explores changes in the career and technical education sector at the K-12 level, suggesting that the sector warrants enhanced attention by those concerned about science, technology, engineering and mathematics (STEM) education in the United States. The sector deserves closer analyses, given how different the education is that it now provides from the vocational emphases of the past. Moreover, the changes in this sector suggest that key aims of STEM education can be achieved through various mechanisms – an important condition in a society marked by substantial diversity. Although there is some systemic work on career and technical secondary schools, the link between them and the world of informal science education remains relatively unexplored. Based, however, on findings from informal science education programs, especially those targeting secondary school youth in comprehensive enrichment programs, there are reasons to conclude that stronger ties between this kind of school and supportive activities outside of the traditional school day could contribute to greater student success. More systematic study of career and technical secondary schools could strengthen our understanding of the various paths through which successful STEM education might be achieved.

Our call for greater cognizance of career and technical education results from two developments. The first: our visit to a highly transformed career school in the Washington, DC area – the Phelps Architecture, Construction and Engineering High School. The second: the conclusion from a recent report that we know far less than is desired about successful schools, and especially about how different attributes of schools matter for different populations of students.[ii] To set the stage for the discussion, we begin with an overview of the challenges associated with STEM education in the United States.

STEM Education Challenges

Several indicators imply that the U.S. is not succeeding in preparing its pre-college students for work and life in a world characterized increasingly by advances in science and technology. Some of the indicators appear in the Program for International Student Assessment (PISA). The Program measures mathematics and science literacy among countries belonging to the Organization for Economic and Cultural Development (OECD). Oft-cited are the outcomes from comparisons undertaken in 2009. The

outcomes: lower average literacy scores in mathematics for students in the United States than the average across the OECD countries. That was the result as well in 2003 and 2006. Although there was improvement from 2006 to 2009, in the latter year the US still lagged behind seventeen other nations.

The scores in science were slightly more encouraging. In 2009, the level of science literacy among U.S. students was comparable to the OECD average and higher than what had been found for the U.S. in 2006. Nonetheless, U.S. students' average scores still fell behind those in twelve of the other OECD countries.[iii]

A bleak picture emerges as well from the National Assessment of Educational Progress (NAEP). In 2009, fourth- eighth- and twelfth-graders were tested in physics as well as the life, and earth and space sciences and were ranked at one of three levels: *basic, proficient, or advanced.* Only 34 percent of the fourth-graders performed at or above the proficient level, meaning that they "demonstrated competency" in difficult material. At the secondary level, eighth- and twelfth-graders' scores at the proficient level were even lower at 30 percent and 21 percent respectively.[iv]

The results from 2009 cannot be compared with those of prior years, due to modifications made to the assessment. What has remained consistent, however, are achievement gaps in science between white students and other racial and ethnic groups. For mathematics, the results are somewhat more encouraging. Although the 2009 data continued to show gaps between population groups, the size of those gaps had narrowed from previous years.[v]

The unfavorable international comparisons have helped promote the development of specialized STEM schools. Although some of the emerging career and technical high schools share selected traits with such specialized schools, contrasts can be found. To highlight the contrasts we sketch first characteristics of special schools for STEM education.

STEM Schools: A Model for Success

Educational researchers, policymakers, parents and other stakeholders often laud the potential of STEM schools, institutions in which STEM disciplines are central and criteria for admissions are selective. The Thomas Jefferson High School for Science and Technology in northern Virginia, founded in 1985 from a collaboration involving the Fairfax County School System and local business, illustrates the specialized school model. The school offers a comprehensive curriculum, which emphasizes critical

thinking skills and the integration of STEM with humanities, as in the IBET (Integrated Biology, English, and Technology) course, a requirement for all incoming freshmen. The freshman class typically includes approximately 480 ninth graders, selected from over 3,300 applicants residing in Arlington, Fairfax, Fauquier, Loudoun and Prince William Counties, in addition to the cities of Fairfax and Falls Church. Thomas Jefferson announces its quest for highly motivated students with good grades (although not necessarily all A's) and "a passion" for STEM.[vi]

The North Carolina School of Science and Mathematics represents another specialized STEM school. This coeducational, residential institution was launched in 1978 by the North Carolina General Assembly to serve junior and senior high school students from all 13 congressional districts in the state. A competitive admissions process selects only an estimated 340 students per class, drawn so as to produce demographic diversity. The college admission rate for graduates: 99 percent. Contributing to the high rate is the grounding the school provides in core subjects, coursework in science, mathematics, computer science, humanities, and laboratory skills as well as in research.[vii]

Not all specialized STEM schools are of recent vintage. The Bronx High School of Science – noted for its four years of laboratory science, three years of mathematics and foreign language, a year of research during the sophomore year, and an extensive array of advanced placement courses – opened its doors in 1938. Today, with over 2900 students, it is one of eight specialized schools serving a diverse group of gifted students from across New York City.[viii]

The Bronx High School of Science and similar institutions belong to a national organization that endeavors to promote collaboration, strong programs in education, research and practice as well as policies to advance such schools. The National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology (NCSSSMST) was established in 1988 to support STEM schools, specifically secondary institutions "…whose primary purpose is to attract and academically prepare students for leadership in mathematics, science, and technology."[ix]

The Vocational School Sector

Phelps High School does not share its history with the Bronx High School of Science or many of the other institutions within the National Consortium. Instead, its roots are in the world of vocational education. Such education traditionally prepared students for the trades – carpentry, welding, and automobile repair, for example. The description of vocational education in Wikipedia portrays its job-centered character. "Vocational education and training prepares trainees for jobs that are based on manual or practical activities, traditionally non-academic, and totally related to a specific trade, occupation or *vocation*. It is sometimes referred to as *technical education* as the trainee directly develops expertise in a particular group of techniques or technology."[x]

Phelps High School emerged as a product of vocational education and of racial segregation in the District of Columbia. Opened in 1933, Phelps provided African American students with training primarily for jobs in construction. The underlying philosophy: "all forms of labor, whether with the head or hand, are honorable."[xi]

But the growing discontent nationally with vocational education and the civil rights movement changed the fortunes of Phelps. Nationally, students from all backgrounds moved away from work-centered education to academic programs offering preparation for higher education. That move was evident in the District of Columbia, resulting in the closure of one vocational school after another.

Reportedly, perspectives from the civil rights movement played directly into the fate of Phelps. A *Washington Post* article reported in 2008 that vocational education sputtered in the civil rights era, "attacked by activists as an attempt to steer black students into blue-collar jobs and out of the college-prep track, where many whites were."[xii] Such attacks undoubtedly made a difference, but even before the civil rights era, it was not uncommon for African American students and their parents to look askance at the offerings at Phelps and the students pursuing them. The emphasis on preparation for the trades simply did not prove alluring to many in the population.[xiii]

Changing conditions, along with declining enrollments, a decaying infrastructure and countless other problems led the District to close Phelps in 2002. The current Phelps Architecture, Construction and Engineering High School, opened in 2008 with an orientation different from what had prevailed earlier.

On Career and Technical Education

The new Phelps differs from its predecessor in its infrastructure as well as its programs. A completely remodeled building houses state-of-the-art laboratories and green technologies that have earned Phelps the designation of LEED Silver Certified Green School. The expertise of such organizations as the Washington Architectural Foundation, Associated General Contractors, and the Mid-Atlantic Regional Council of Carpenters contributed substantially to the planning for the modern structure of Phelps.

Programmatically, Phelps reflects the transition of vocational education to career and technical education, or CTE. This form of education aims to "empower students for effective participation in a global economy as world-class workers and citizens."[xiv] It focuses heavily on the content of courses, aiming to provide students with the knowledge needed for additional academic work or immediate employment.

The CTE emphasis at Phelps appears in the eight majors the school offers, ranging from architecture to welding and sheet metal. The latter subjects have parallels with vocational education in the past. That is not the case for the major in architecture or for what the Cisco Networking Academy offers. In a dedicated CADD laboratory, students can try their hands at design or use joysticks and flat screen monitors to develop and assess their skills for operating cranes in the heavy equipment laboratory. Students learn about sustainable technologies by monitoring energy from photovoltaic solar arrays, wind turbines, and a geothermal cold-water loop that are part of Phelps' infrastructure.

The technologies and laboratories now available place the students light-years away from their predecessors at Phelps. But in their courses, the students are exposed to the conceptual knowledge found in the programs outside of the CTE sector, since the school offers a complete college preparatory program as well. In addition, the hands-on instruction, the simulations, and the design work give the students the authentic encounters often associated with preparation for and inspiration in STEM education. Such engagement could be especially significant for students likely to have limited experiences with STEM activities outside of the school setting or for those who might consider pursuing STEM degrees at the college level.

The recent study from the National Research Council (NRC) on successful schools described CTE schools as major contenders in today's STEM school arena. Unfortunately, the research base is limited for all types of STEM schools, including those within the CTE orbit. We offer our

impressions of the contributions CTE schools can make, based on our understanding of programming at Phelps. Those impressions cannot substitute, of course, for systematic study on how such schools in fact prepare students for citizenship and work in a world where innovation is sought.

Beyond the School

For many students experiences outside of the school setting reinforce the learning pursued within the borders of the institution. For others, STEM-related activities are highly constrained outside of those borders and they may benefit from additional access. The NRC publication, *Learning Science in Informal Environments: People, Places and Pursuits,* notes that informal learning encompasses experiences in non-school environments that can be characterized as lifelong, life-wide, and life deep. A broad range of venues and social settings may serve as hubs for informal STEM learning including museums, science centers, zoos, aquariums, libraries, community settings, and also the home.[xv] The potential of the informal sector to strengthen STEM education accounts for programs the National Science Foundation supports through the Division of Research on Learning in Formal and Informal Settings (DRL). Next we provide a brief discussion of theories and perspectives associated with informal learning programs and sample strategies, while considering the potential for collaboration with schools.

Theoretical Perspectives and Program Designs

Informal science education programs are often informed by sociocultural theories of learning, which focus on learning in context; addressing cultural issues important to learning; and extending the notion of learning beyond the accumulation of facts to include participation, identity, access, and engagement. Students take an active role in their learning as they co-construct knowledge with mentors in learning communities.[xvi] Additionally, the use of authentic learning experiences that make connections to day-to-day activities and promote learning across contexts provide a seamless connection between informal and formal learning.[xvii] The NRC report on informal learning also cites the use of sociocultural perspectives to support project designs, which are often supplemented by cognitive learning theories and positive youth development approaches. Additionally, a summary of study findings indicates positive impacts on youth STEM and career interests, in addition to academic gains, although

there is still a reliance on a wide assortment of evaluations to support impacts associated with cognitive gain and skill development.[xviii]

Interestingly, several parallels can be found between the aims of CTE and informal learning programs for youth such as promoting interest in STEM and STEM careers and providing authentic learning experiences. Like their formal education counterparts, informal youth programs frequently emphasize approaches that research suggests are important for steering students into STEM career paths, by building on interest during early adolescence and offering intensive research experiences during high school.[xix, xx] Many of the projects target youth who are underserved and underrepresented in STEM, who would not normally have access to high quality informal science experiences.

In a longitudinal study of urban girls participating in a year-round natural science enrichment program, the participants credited the program activities, including classes, field trips, and STEM content with influencing their educational and career paths. While all students did not pursue STEM majors, the college enrollment rate exceeded 93 percent.[xxi] Youth programs that enable participants to make contributions to their community through work experiences and examination of environmental issues are also common. Apprenticeship models commonly used in CTE schools are adopted in non-school contexts because they enable students to learn about the culture and practice of science, develop identities as scientists, use the language of science in a supportive environment, develop in-depth understanding of concepts, and access diverse tools.[xxii] Not surprisingly, social media is a frequently utilized mechanism for supporting STEM learning in informal settings.[xxiii]

Collaborations with Schools

Recognizing the growing interest in and potential associated with learning in informal learning settings, in 2007, NSF funded a demonstration project designed to capitalize on the strengths of both formal and informal learning settings. The Academies for Young Scientists (AYS) program targeted students in grades K-8, and the 16 projects had the common goal of integrating STEM across learning contexts for the express purpose of augmenting interest and awareness of STEM careers.[xxiv] At a culminating conference, several important trends emerged that may contribute to the existing repertoire of findings related to informal STEM learning. Like many informal science education experiences, activities were tailored to meet the needs of the local population, allowing for a great deal of

flexibility in design and scaffolding to support participant interest and exploration in STEM. The programs were structured to allow for voluntary, self-directed learning that is not typically a hallmark of classroom STEM instruction, resulting in enrichment experiences for students at both ends of the academic spectrum – those who are in need of additional STEM experiences as well as students who already exhibit some mastery in the subject matter. For example, participation in AYS programs was often associated with engagement of youth who were not highly motivated by "school STEM" which was enlightening for their classroom teachers.[xxv]

Collaborations between formal and informal science education institutions such as those in AYS are of interest to many. The Center for Advancement of Informal Science Education (CAISE), released a report in March 2010 focused on this very topic. The report emphasized the benefits of such collaborations including stronger science programs that incorporate best practices associated with informal settings, emergent learning communities, and increased equity and access for those who may be underserved and underrepresented in STEM.[xxvi]

Despite the inference that informal science learning programs may have some goals in common with CTE schools, there is little empirical evidence at this time to support this claim or the suggestion that there might be some benefit to a closer association between the two. However, the potential for informal science education to strengthen the science learning in schools is an idea that has wide appeal.

Summary

CTE schools offer excellent examples of interventions that can be utilized to meet the goal of preparing young people to enter the future STEM workforce. As these schools continue to emerge as educational exemplars, they may offer models that can support STEM education goals. Informal science learning also continues to gain prominence, as an analysis of research provided solid evidence that learning occurs in nonschool settings through "everyday experiences, designed settings, and programs."[xxvii] Several federal reports have lauded the strengths of high quality informal science education programs, including the ability to foster increased interest, motivation, and the pursuit of STEM education and career trajectories in youth from diverse backgrounds and under-resourced communities.[xxviii, xxix]

The prevailing theme among educators and policymakers appears to be that the full responsibility for the preparation of a STEM literate citizenry

should not fall upon schools, even well-equipped STEM and CTE schools, especially when nonschool activities are an untapped resource for cultivating student interest and engagement in STEM. All that remains is to address the paucity of research that exists to document the impacts of informal STEM experiences and the cumulative impacts of rich collaborations between schools and informal science education institutions. More research is needed to understand CTE schools and other novel approaches to STEM education and workforce preparation utilized in both formal and informal learning environments, which are of particular benefit to students who have traditionally been underserved in STEM.

Notes

[i] U. S. Department of Labor, The Secretary's Commission on Achieving Necessary Skills. (1991). *What work requires of schools: A SCANS report for America 2000.* Retrieved from http://www.scans.jhu.edu/NS/HTML/AboutCom.htm

[ii] National Research Council. (2011). *Successful K-12 STEM Education: Identifying effective approaches in science, technology, engineering and mathematics.* Washington, DC: The National Academies Press.

[iii] OECD. (2010). *PISA 2009 at a glance*. Retrieved from http://dx.doi.org/10.1787/9789264095298-en

[iv] National Center for Education Statistics. (2010). *The nation's report card: Grade 12 reading and mathematics 2009 national and pilot state results* (NCES 2011-455). Washington, DC: U.S. Department of Education.

[v] National Center for Education Statistics. (2011). *The nation's report card: Science 2009* (NCES 2011–451). Washington, DC: U.S. Department of Education.

[vi] Thomas Jefferson High School for Science and Technology. (2011). *About TJ.* Retrieved from http://www/tjhsst.edu/

[vii] North Carolina School of Science and Mathematics. *2010-2011 Profile.* Retrieved from http://www.ncssm.edu/

[viii] The Bronx High School of Science. (2011). Retrieved from http://www/bxscience.edu/

[ix] National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology. (2006). *Overview.* Retrieved from http://www.ncsssmst.org/default.aspx

[x] Wikipedia. (2011) *Vocational Education.* Retrieved from http://en.wikipedia.org/wiki/Vocational_education

[xi] (2011) *Education Design Showcase.* Retrieved from http://www.educationdesignshowcase.com/view.esiml?pid=247&lastsearch=grade%5Fid%3D7

[xii] Haynes, V. D. (2008, May 11). "*At D.C. Phelps high, a return to the future.*" *Washington Post.* Retrieved from http://www.washingtonpost.com/wp-dyn/content/article/2008/05/10/AR2008051002360.html

[xiii] For example, one of our group, Howard Goines, had attended the DC public schools and attested to the disdain his classmates sometimes expressed towards Phelps.

[xiv] Cumberland County Schools. (2011). *Career and technical education.* Retrieved from http://www.cte.ccs.k12.nc.us/

[xv] National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits.* Washington, DC: The National Academies Press.

[xvi] Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

[xvii] Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* New York, NY: Cambridge University Press.

[xviii] National Research Council. See note xv.

[xix] Roberts, L. F. & Wassersug, R. J. (2009). Does doing scientific research in high school correlate with students staying in science? A half-century of retrospective study. *Research in Science Education, 39,* 251-256.

[xx] Tai, R. H., Liu, C. Q., Maltese, A. V. & Fan, X. (2006). Planning early for careers in science. *Science, 312*: 5777, 1143-1144.

[xxi] Fadigan, K. A. & Hammrich, P.L. (2004). A longitudinal study of the educational and career trajectories of female participants of an urban informal science education program. *Journal of Research in Science Teaching, 41:*8, 825-860.

[xxii] Richmond, G., & Kurth, L. A. (1999). Moving from outside to inside: High school students' use of apprenticeships as vehicles for entering culture and practice as science. *Journal of Research in Science Teaching, 36*(6), 677-697.

[xxiii] Bull, G., Thompson, A., Searson, M., Garofalo, J., Park, J., Young, C., & Lee, J. (2008). Connecting informal and formal learning: Experiences in the age of participatory media. *Contemporary Issues in Technology and Teacher Education, 8*(2). Retrieved from http://www.citejournal.org/vol8/iss2/editorial/article1.cfm

[xxiv] National Science Foundation. (2006). *Academies for young scientists* (NSF 06-560). Retrieved from http://www.nsf.gov/pubs/2006/nsf06560/nsf06560.htm

[xxv] Bevan, B., Michalchik, V., Bhanot, R., Rauch, N., Remold, J., Semper, R., & Shields, P. (2010). *Out-of-school time STEM: Building experience, building bridges*. San Francisco: Exploratorium.

[xxvi] Bevan, B., Dillon, J., Hein, G.E., Macdonald, M., Michalchik, V., Miller, D., Root, D., Rudder, L., Xanthoudaki, M., & Yoon, S. (2010). *Making science matter: Collaborations between informal science education institutions and schools. A CAISE inquiry group report.* Washington, DC: Center for Advancement of Informal Science Education (CAISE).

[xxvii] National Research Council. See note xv.

[xxviii] National Science Board. (2010). *NSB Report: Preparing the Next Generation of STEM Innovators.* Retrieved from http://www.nsf.gov/nsb/publications/pub_summ.jsp?ods_key=nsb1033

[xxix] President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

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Editor's Comments

I am excited to present to you the Winter 2011 issue of the Journal of the Washington Academy of Sciences, which focuses on service-learning. Honestly, before this issue, I had never heard of the term service-learning. It is a hands-on, integrated approach to learning that connects students with their community and fosters a cooperative partnership for reciprocal learning; both the community and the student benefits.

This issue focuses on the service-learning program that is on-going at George Washington University. The first article introduces the theory and history behind service-learning, to get the reader familiar with the subject at hand. The second article illustrates a specific example of the use of service-learning in an undergraduate classroom at GWU. Finally, the third article introduces the reader to the use of service-learning internationally, emphasizing both the benefits and the challenges in implementing such a program abroad.

My hope is that this issue will familiarize you with service-learning, and perhaps inspire you to consider service-learning in your own lives as academics, scientists, and community members. While reading these articles, I was reminded of my first job after graduating from my undergraduate institution. It wasn't until I applied my training to hands-on activities (*i.e.* my first job out of college) that I really solidified my understanding of these principles. Service-learning is a means of introducing this hands-on application earlier, to enhance the student's learning experience, as well as foster a lasting relationship with community interests. Although we focus here on undergraduate and graduate applications, this is a learning technique that can be applied at any age.

Further information can be found at: George Washington University's Center for Civic Engagement and Public Service http://www.gwu.edu/explore/campuslife/studentinvolvement/serviceengagement/servicelearning and The National Service-Learning Clearinghouse http://www.servicelearning.org /

Enjoy!
Jacqueline Maffucci

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Service-Learning as a Method of Instruction

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Abstract

Service-learning is a new educational method that is expanding the involvement of universities in their neighboring communities. It also tends to promote the civic and moral development of students. This paper explains what service-learning is and how it is consistent with the history of universities in general and particularly universities in the U.S. with their focus on applied knowledge. The paper describes how service-learning has developed in the U.S. and how it is practiced in a School of Business. The article presents some important lessons learned from conducting service-learning at The George Washington University.

Service-Learning Defined

Service-learning is now being practiced at many levels of education in the United States. Common service-learning activities include the following: Middle school students (11-14 years old) may help to clean up a part of the city and then write essays about keeping the city clean or the importance of caring for the environment. High school students (15-18 years old) sometimes help to deliver meals to elderly or terminally ill people and then write essays on what life is like for people in different stages of life. Undergraduate and graduate students in the School of Business at The George Washington University often do group projects with local organizations. Students in management work in teams of 3 to 5 as consultants to non-governmental organizations (NGOs), government agencies or businesses. These projects are the "laboratory" part of a management course. The client is a second instructor. Students have an opportunity to observe an organization while helping the organization to improve its processes. Students write a paper in which they describe the work they did and use as many concepts from the course as they can, thereby connecting the concepts in the textbook with their personal experiences.

Service-learning can be defined as "service performed by students, aimed at attending to a real need of the community, and oriented in an explicit and planned way to enhance the quality of academic learning." (Tapia, *et al.*, 2006, p. 68) A service experience should be personally

meaningful and beneficial to the community. In addition, there should be clearly identified learning objectives, student involvement in selecting or designing the service activity, a theoretical base, integration of the service experience with the academic curriculum and opportunities for student reflection. (Furco and Billig, 2002, pp. 7-8)

Individuals may cognitively process knowledge in one of four ways: personal experiences, reflective observations, abstract conceptualizations, or active experimentations. Based on their personalities, individuals may prefer one learning style over another. A major strength of service-learning projects is that they contain both personal experiences and reflective opportunities. Thus students are likely to be responsive to service-learning activities regardless of their learning style. (Lester, *et al*., 2005, p. 279)

Three reasons can be given for encouraging service-learning: aid the community, more effective learning and moral development. Advocates of service-learning argue that a key value of service lies in its ability to foster heightened moral awareness. Service-learning projects expose students to community needs. Service activities are an opportunity to infuse the message that organizations can "do well by doing good." Service-learning experiences therefore can be seen as an instructional technique that encourages individuals to be socially responsible and engage in moral actions. (Lester, *et al*., 2005, p. 279)

Service-learning is not simply a pedagogy. Rather, service-learning is a means to empower students and educational institutions to become more aware of the needs of the communities of which they are a part and to become engaged and civically active in mutually beneficial ways. Community-based service that relates to course and curricular content is becoming increasingly embedded in curricula. Evidence is beginning to show that service-learning has not only begun to transform education, but it also has transformed the lives of many of the students involved. (Casey, *et al*., 2006, p. xi)

An Historical Commitment to Community Service

Universities have a long history of making important contributions to their surrounding communities. European universities emerged in decentralized medieval society and became more widespread in the fifteenth and sixteenth centuries due in part to actions by city authorities and regional authorities. Universities were supported because of the

recognition that the growth and dissemination of knowledge was of value to the community. (Florax, 1992, pp. 275-276)

The U.S. has a tradition of people organizing efforts to serve public interests. In his famous nineteenth century study of American society, de Tocqueville noted Americans' habit of forming voluntary associations to advance their own and the community's interests. De Tocqueville suggested that such associations were crucial to the vitality of American society, pointing out that their activities served to shape the participants' recognition of the coincidence of personal and public interest, which he called "the principle of interest rightly understood." (Pritchard, 2002, p. 4)

Universities in the U.S. have been said to engage in the three activities of education, research and service. The role of universities in providing service to society beyond simply educating the next generation has a long history. In 1862, the U.S. government passed the Morrill Act, which established agricultural and engineering extension services at state universities. Under this act, the federal government gave land to the states. The states were to sell the land and use the money to buy stocks that would generate perpetual income to support the universities. The universities were to teach students, conduct research on improved methods, and communicate the results of the research directly to farmers and businessmen through "extension agents." Extension agents were similar to traveling salesmen for new agricultural and engineering methods. Hence, the activity of service was changed and universities took a more active role in providing service to society.

Students and faculty members at U.S. universities have been doing volunteer work with community organizations for many years. For example, Russell Ackoff, his colleagues and students worked not only with business clients but also with community leaders in the neighborhoods near the University of Pennsylvania. (Ackoff, 1974) These consulting activities were discussed in class and were part of the curriculum. However, the rapid growth of service-learning as a teaching method is rather recent. The growth of service-learning in the U.S. can be described as passing through several stages.

1. Students have long worked in groups to complete a large assignment. This method of learning is a step beyond lectures, exams, and term papers.
2. At least by the 1970s some students were doing projects which were not just hypothetical projects or laboratory exercises. Rather, students worked on projects with real clients with real problems.

3. The term "service-learning" was invented and defined as a pedagogical method.
4. Books and articles on service-learning began to appear in the educational literature.
5. Articles on service-learning began to appear in discipline-oriented journals. Hence, publications about service-learning spread beyond schools of education to the journals of other disciplines.

Increased attention to service in the educational curriculum arises at a time when modern industrial economies have become more knowledge intensive. Universities are important social institutions that contribute to economic growth. So, combining education, research and service, rather than keeping them separate is arising in part due to an effort to couple the knowledge creating activities of the university more closely to the community.

"From community colleges to major research universities, relations to surrounding communities are central to the higher educational agenda. The institutions of higher education profiled in this book are using various strategies to revitalize local neighborhoods while concurrently fulfilling some aspect of their educational mission." (Maurrasse, 2001, p. 181) Service-learning is one example of this heightened commitment to community service.

Another reason for the spread of service-learning is the motivations of faculty members.

I started assigning group projects with real clients in 1978, soon after arriving at GW. Although there certainly is a role for textbook problems, I feel that students learn more from working on real problems than on hypothetical problems.

One indication of the spread of service-learning in the U.S. is the growth in membership of Campus Compact, which was founded in the mid 1980s by the presidents of three universities – Brown University, Georgetown University and Stanford University. Their intent was to persuade the presidents of other universities to encourage faculty, students and staff to engage in service activities. The "compact" is a statement that university presidents are asked to sign. If the president signs then that university becomes a member of Campus Compact (www.compact.org) and becomes publicly committed to engaging in service-learning activities. Figure 1 shows the growth in the number of university presidents who have signed the compact since 1985.

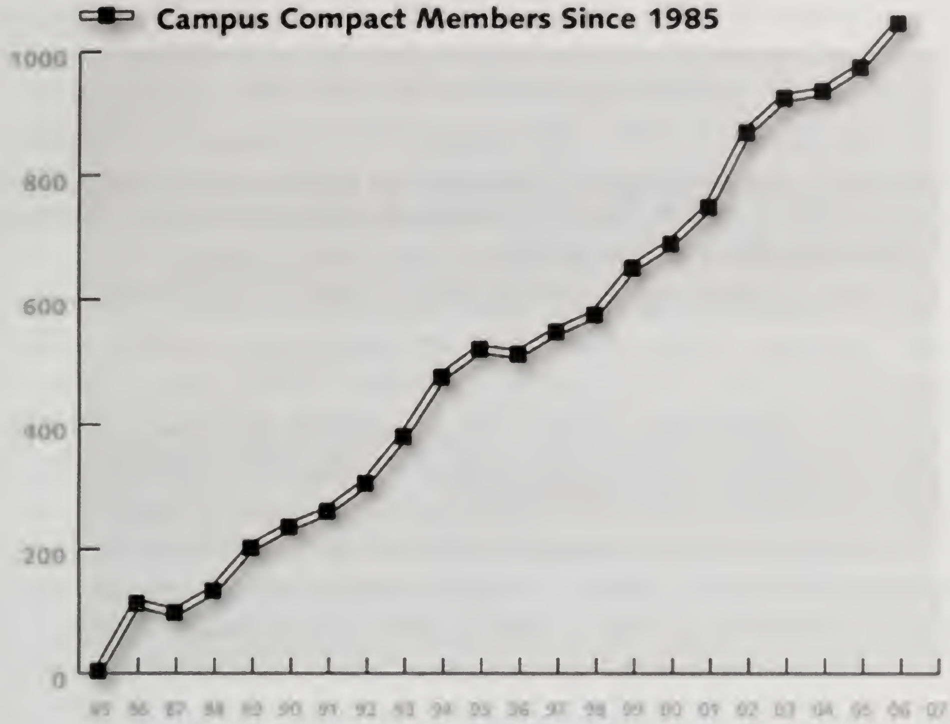

Figure 1: The Growth of Campus Compact

The American Emphasis on Applied Knowledge

Service-learning can be seen as an extension of a long-standing commitment in the U.S. to practical knowledge. Some countries emphasize theoretical knowledge to the neglect of applied knowledge. Richard Feynman, who won a Nobel Prize in physics, described his experience of teaching in Brazil. He was puzzled by the observation that his students could answer some questions quickly and accurately, but other questions, which seemed the same to him, they could not answer at all.

> After a lot of investigation, I finally figured out that the students had memorized everything, but they didn't know what anything meant. When they heard "light that is reflected from a medium with an index," they didn't know that it meant a material such as water… Everything was entirely memorized, yet nothing had been translated into meaningful words. (Feynman, 1984, pp. 212-213)

Service-learning provides a way of relating textbook assignments and classroom discussions to personal experiences.

Thomas Ehrlich, former president of Indiana University and former chair of Campus Compact, has described a debate over the nature of a liberal education which occurred in the U.S. in the 1930s. On one side was Robert M. Hutchins, president of the University of Chicago and his colleague Mortimer Adler. They argued for focusing the undergraduate curriculum on a selection of "Great Books." They claimed that the study of the works of major Western thinkers would lead to a set of principles covering all aspects of human life.

On the other side philosopher John Dewey argued that this claim was dangerous because the notion of fixed truths requires a seal of authenticity from some human authority, which leads away from democracy and toward fascism. He also argued that purely intellectual study should not be separated from practical study or from the great practical problems confronting society.

Such separation can only weaken the intellect and undercut the resolution of those problems. Study Aristotle, Plato, Aquinas, and the others, Dewey urged, but recognized that contemporary learning from their writings requires the application of their insights to contemporary issues… At the time of the debate and for most of the next half-century leaders in higher education generally concurred that Hutchins won the argument. The premise of service-learning is…. however, that Dewey was right and Hutchins was wrong. Service-learning is the various pedagogies that link community service and academic study so that each strengthens the other. The basic theory of service-learning is Dewey's: the interaction of knowledge and skills with experience is key to learning. (Ehrlich, 1996, pp. xi-xii)

Service-learning is one of several trends in pedagogy that together mark a shift in undergraduate education from an emphasis on teaching to one on learning. Among the other trends are a focus on problems rather than disciplines, an emphasis on collaborative rather than individual learning, …. and careful articulation of learning outcomes coupled with assessment of learning success. (Ehrlich, 1996, p. xiii)

Robert Coles (1993) makes the case for the impact on moral character that derives from community service in conjunction with guided reflection, a necessary ingredient of service. Service-learning can enhance interpersonal skills that are key in most careers – skills such as careful listening, consensus building, and leadership. Dewey wrote that education should be the primary means of social progress, not just a means to develop the intellect for its own sake. Democracy depends on an involved

citizenry. Lee Shulman suggested in 1991 that service learning may become the "clinical practice of the liberal arts." (Ehrlich, 1996, p. xv)

The Benefits of Service-Learning

Service-learning is now being studied from several points of view, depending on the interests of researchers. Key topics that are being discussed concern implementation of service-learning in curricula, methods of implementation, establishment of collaboration with the community, and benefits of service-learning for all parties (students, faculty, community and educational institution).

The motivation of faculty members to adopt service-learning as a method of instruction has been studied by Barbara Holland (2003). She found that there are different sources of faculty motivation. Faculty members might be motivated by personal values, values that inspire their commitment to a life of service, the success of their discipline and the quality of their teaching and research. Hence, service-learning and collaboration with the community can be a result of either individual or professional goals.

Measuring the outcomes of service-learning for the various parties has been attempted by many authors. In their studies, they pay most attention to the outcomes for students. The most difficult to measure or identify are the outcomes for educational institutions. The benefits for the community are obvious. Students do work that would increase the expenses of community organizations if the work were done by employees or professionals who were paid for their work. Clearly, both students and client organizations benefit. Some participants benefit more than others but certainly implementation of service-learning as part of a course will have positive impacts on students, faculty, community and educational institutions.

Janet Eyler and her colleagues have summarized the research on service-learning in higher education over the past few years. Among their findings, each of which is annotated with references, are the following:

- Service-learning has a positive effect on student personal development such as sense of personal efficacy, personal identity, spiritual growth, and moral development.
- Service-learning has a positive effect on interpersonal development, the ability to work well with others, and leadership and communication skills.

- Service-learning has a positive effect on reducing stereotypes and facilitating cultural and racial understanding. However, a few studies suggest that service-learning may subvert as well as support course goals of reducing stereotyped thinking and facilitating cultural and racial understanding.
- Service-learning has a positive effect on sense of social responsibility and citizenship skills.
- Students and faculty report that service-learning has a positive impact on students' academic learning.
- Students and faculty report that service-learning improves students' ability to apply what they have learned in the "real world."
- Service-learning participation has an impact on such academic outcomes as demonstrated complexity of understanding, problem analysis, critical thinking, and cognitive development.
- Students engaged in service-learning report stronger faculty relationships than those who are not involved in service-learning.
- Service-learning improves student satisfaction with college.
- Students engaged in service-learning are more likely to graduate.
- Faculty using service-learning report satisfaction with quality of student learning. They report commitment to research. They increasingly integrate service-learning into courses.
- Colleges and universities report that community service positively affects student retention and enhances community relations.
- Communities report satisfaction with student participation and enhanced community relations. (Eyler, *et al*., 2003, pp. 15-19)

Implementation of Service-Learning

Service-learning in the curriculum can be implemented in several ways. (Enos and Troppe, 1996) Service-learning can be a fourth-credit option (add a fourth credit to a regular three-credit course), a stand-alone module (three credits) or part of a normal course. In terms of its place in the curriculum, service-learning can be incorporated into an introductory course, a required course, or an elective course. Service-learning can be included as course clusters, as capstone projects, *etc.* Each university needs to adjust the implementation of service-learning depending on the field and the abilities of students. Service-learning can be implemented in every field but not in every course.

Establishing partnerships between a university and the community is very important. Partnerships are usually established in three stages: designing partnerships based on values, building collaborative working relationships among partners, and sustaining the partnerships. (Torres and Schaffer, 2000) In many service-learning activities students work as individuals on tasks arranged by leaders of non-governmental organizations (NGO) and university administrators. However, in graduate management classes students often do group projects with organizations where one student is employed.

Service-learning at The George Washington University

Service-learning is widely practiced at The George Washington University. In the past few years, more than 30 faculty members in 17 departments have integrated service–learning into their course offerings. (Benton-Short and Morrison, 2007, pp. 4-5) The Center for Civic Engagement and Public Service is the clearinghouse for service-learning activities at The George Washington University. The Center's staff members work to support service-learning across all academic departments by providing resources, support, and information to faculty, students, administrators and community partners. The staff has established more than 60 campus-community partnerships with local schools, agencies, and community organizations. Faculty engaged in service-learning may access the Center as a resource for identifying a community partner for service-learning projects. (Benton-Short and Morrison, 2007, pp. 8-9)

Benefit to Students

By doing group projects students experience the psychological sequence of working in a team – forming, storming, norming, and performing. (Tuckman, 1965) Students are able to apply what they have learned in the classroom. They gain experience with organizations and the problems they face. They learn not only to solve well-formulated textbook problems but also to identify ill-defined problems in an organizational setting. Students gain confidence in their ability to solve organizational problems.

The Assignment

Service-learning courses contain key elements that set them apart from traditional classes. The main differentiator of a service-learning course is that part of the course occurs outside of the classroom and in the community. Service-learning courses possess a greater amount of complexity in terms of the number of stakeholders involved and the quality, resonance, and nature of knowledge transfer and competence building. Within a service-learning course, a student's learning will go beyond the course subject matter to include capacity building, team work, leadership, communication and citizenship. (Faculty Service–Learning Toolkit, 2007)

Students in the School of Business at GW are doing service–learning projects as part of some courses. The assignment is to improve the functioning of some organization. The students use the knowledge and methods that they have acquired from the textbook and classroom discussions. Before the students start to work on a project, the professor provides specific guidelines and recommendations on how to do the project. These guidelines help students do the project effectively. See the website http://www.gwu.edu/~rpsol/service-learning.

Students also receive instructions for working on the project effectively and achieving the project goals. At the end of the semester, when students finish the project, they prepare a final report which is presented both to the client and in class in front of their classmates. Students are given instructions on how to prepare the final report. The client completes an evaluation form and sends it to the instructor. The guidelines help students to develop an appropriate path for doing the projects so they do not lose time. The guidelines also make the projects more comparable.

Types of Projects

From 1992 to 2007 my students worked on 70 projects for different clients – local and state government, nonprofit organizations, businesses, and universities. The projects can be classified according to the type of organization. The distribution of the projects in terms of numbers and percentages is listed in Table 1. (Levkov and Umpleby, 2009)

Table 1: Clients of student projects

Clients	Numbers	Percentage
Businesses	24	34%
Federal government agencies	4	6%
Local government agencies	6	9%
Universities	19	27%
Non – profit organizations	17	24%
Total	70	100%

Students used their skills and knowledge to do different kinds of tasks in their project activities. Short descriptions of a few projects show a wide range of activities:

- An international non-governmental organization needed help finding specific solutions to improving processes in the areas of marketing, strategic management, and human resources.
- Students worked with a U.S. government agency to incorporate improvements into the new budget development process for the fiscal year 2008 budget cycle.
- A department of the city government sought recommendations for the proposed restructuring of the information systems department and suggestions for how the staff could keep their technical skills current.
- Students worked with a U.S. government agency to find the best governance model for managing a web portal.
- Students worked with an office at GW to create a mentor program for incoming, international students pursuing an undergraduate degree.

Choosing a Project

There are several possible ways that students can find a project. Students can be assigned a project by the instructor, they can choose a project from a list of possible projects or they can find a project through their work place or through friends. In my classes, students usually work with an organization where one student is employed. I also suggest possible projects and clients.

Depending in part on the class the students do a wide variety of projects, for example improving office procedures, creating a cross-cultural training program, revising personnel procedures, conducting a

survey of customers or employees, building a website, or guiding a strategic planning process.

Integration of the Internet into Service-Learning

Email has made it much easier for students to work together on a project. Since the internet is now worldwide, students are choosing to do projects with clients in other countries. Usually the client is a friend or relative of a student in the group. Here are a few examples of international projects.

- One member of a group was a Korean student who had a brother who worked in Mexico. The brother's firm made auto parts at a factory in Mexico. The Korean managers were having difficulty communicating with the Mexican workers due to cultural differences. So, in a Cross-cultural Management class a group of students created a training program for the Korean managers and Mexican workers, so they would better understand the cultural differences between Korea and Mexico.
- A group of students in an organizational behavior course worked with Somali television. Somalia was a failed state. For several years it had had no government, because the Somali government officials had moved to Kenya to avoid the chaos in Somalia. But many organizations continued to function, including Somali television. The owner lived in London. My students worked with the owner via email on two projects. First, they found a code of journalistic ethics, which was used in training the journalists in Somalia. Second, they obtained an organization chart from a television station in Washington, DC, and sent it to the owner in London along with recommendations on how to organize the people working at the station in Somalia.
- A student from Ethiopia shared the class notes on quality improvement methods with the Ethiopian government official in charge of quality improvement in Ethiopia. Via email she explained the class notes and provided additional books and articles.

Lessons learned

The work of the students is invariably rated very highly by the clients. What students are able to accomplish in one semester is quite impressive. The most frequent suggestion from clients is that students should work with them more closely.

When projects are conducted by graduate students, usually they decide to work with an organization in which one or more students are working. Several benefits result when the student chooses the client:

- Increased trust between the students and the client
- Better collaboration
- More knowledge of the organization and the processes and problems within the organization
- Less difficulty defining and analyzing the problems and developing solutions
- A greater likelihood that the recommended changes will be implemented, because essential support for implementation continues with the student employee.

We have also learned that projects work better when the person desiring that the project be done is the same person the students work with. In the DC government projects we found that sometimes a superior wanted the project to be done, but the students worked with a person lower in the chain of command. In these cases the immediate client often seemed to feel that the students were there to observe and to report to the higher level manager. This perception sometimes led to non-cooperation, which interfered with completing the project in a timely fashion.

Conclusion

In the United States service-learning has proven to be an effective means both for education and for community development. Service-learning is a new pedagogical method which is spreading rapidly in the U.S. and in other countries. Research shows that it improves the effectiveness of education and has a beneficial effect on students' sense of social responsibility. The work that students do is beneficial to neighboring communities and organizations. Service-learning aids learning, is a way for universities to contribute to their communities, and helps to instill democratic values.

References

Ackoff, Russell L. (1974). *Redesigning the Future: A Systems Approach to Societal Problems.* New York: Wiley.

Benton-Short, Lisa and Emily Morrison. (2007). "Service-Learning Advisory Board Report on Service-Learning," A working paper, The George Washington University, Washington, DC.

Casey, Karen McKnight, *et al.* (2006). *Advancing Knowledge in Service-Learning: Research to Transform the Field.* Greenwich, CT: Information Age Publishing.

Coles, Robert. (1993). *The Call of Service: A Witness to Idealism.* Boston: Houghton Mifflin.

Ehrlich, Thomas. (1996). "Forward," in Jacoby, Barbara (ed.). *Service-Learning in Higher Education: Concepts and Practices.* San Francisco: Jossey-Bass, pp. xi-xvi.

Enos, Sandra L. and Marie Troppe. (1996). "Service-Learning in the Curriculum," in Barbara Jacoby and Associates (eds.), *Service Learning in Higher Education: Concepts and Practices,* San Francisco: Jossey-Bass.

Eyler, Janet S., *et al.* (2003). "At a Glance: What We Know About the Effects of Service-Learning on College Students, Faculty, Institutions, and Communities, 1993-2000," in Campus Compact. *Introduction to Service-Learning Toolkit: Readings and Resources for Faculty.* Second Edition. Providence, RI: Brown University, pp. 15-19.

"Faculty Service-Learning Toolkit," (2007). Community Campus Partnership for Health and National Service–Learning Clearinghouse.

Feynman, Richard P. (1984). *"Surely You're Joking, Mr. Feynman!": Adventures of a Curious Character.* New York: W.W. Norton and Company.

Florax, Raymond. (1992). *The University: A Regional Booster? Economic Impacts of Academic Knowledge Infrastructure.* Brookfield, VT: Ashgate Publishing.

Furco, Andrew and Shelley H. Billig (eds.). (2002). *Service-Learning: The Essence of the Pedagogy.* Greenwich, CT: Information Age Publishing.

Holland, Barbara. (2003). "Factors and Strategies that Influence Faculty Involvement in Public Service," in Campus Compact. *Introduction to Service-Learning Toolkit: Readings and Resources for Faculty.* Providence, RI: Brown University, pp. 253-256.

Lester, Scott W., *et al.* (2005). "Does Service-Learning Add Value. examining the Perspectives of Multiple Stakeholders," in Academy of Management *Learning and Education*, Special Issue: Service-Learning, Vol. 4, No. 3, pp. 278-294.

Levkov, Nikola and Stuart Umpleby. (2009). "How Service-Learning is Conducted in a School of Business," in *CEA Journal of Economics*, Vol. 4, No. 2, pp. 26-34, Center for Economic Analyses, Skopje, Macedonia.

Maurrasse, David J. (2001). *Beyond the Campus: How Colleges and Universities Form Partnerships with Their Communities.* New York: Routledge.

Pritchard, Ivor A. (2002). "Community Service and Service-Learning in America: The State of the Art," in Furco, Andrew and Shelley H. Billig (eds.). *Service-Learning: The Essence of the Pedagogy.* Greenwich, CT: Information Age Publishing.

Tapia, Maria Nieves, *et al.* (2006). "Service-Learning in Argentina Schools", in Casey, Karen McKnight, *et al.* (eds.). *Advancing Knowledge in Service-Learning: Research to Transform the Field.* Greenwich, CT: Information Age Publishing.

Torres, Jan and Julia Schaffer. (2000). "Benchmarks for Campus/Community Partnerships," in Campus Compact. *Introduction to Service-Learning Toolkit: Readings and Resources for Faculty.* Providence, RI: Brown University, pp. 101-104.

Tuckman, Bruce. (1965). "Developmental Sequence in Small Groups," in *Psychological Bulletin.* **63** (6): pp. 384-99.

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Preparing "academic citizens:" Service-learning in Research Universities

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Abstract

Service-learning is often promoted as a way of increasing civic engagement and concern for public life. While these are excellent goals, their prominence may obscure the ways that service-learning benefits students as burgeoning scholars. I argue that conducting research with and for community organizations helps students understand that academic work is accountable to both public and academic communities. At the same time, comparing the community-building strategies of both public and academic communities introduces students to the rhetorical moves by which scholars signal their disciplinary affiliations. A reflexive approach to service-learning emphasizes students' roles as scholars as much as it emphasizes their role as citizens.

Introduction

As a philosophy of teaching embraced across many disciplines, service-learning is employed to promote students' civic and academic engagement. Studies of K-12 service learning programs show that students who participate in service-learning are more politically engaged, more tolerant of others, and even fifteen years later are more likely to remain active in community work and to vote than those who do not participate in such classes (Corporation for National and Community Service 2007). Moreover, students develop better problem-solving skills, understand complex ideas more fully, feel more connected to their schools, and receive higher grades on content area tests (Corporation for National and Community Service 2007). When college students take service-learning classes, they have better attitudes, skills, and more understanding of social issues (Eyler, Giles and Braxton, 1997).

As a strategic institutional initiative, the growth of service-learning can be understood as a response to the broader public portrayal of "the academy" as a distant, elite place that is out of touch with the "real world." In times when public budgets are highly scrutinized, research pursuits that are seen as too cerebral are regularly ridiculed by those who would have universities focus on pragmatic concerns. Articles written for specialized academic journals are criticized for their dense, academic language and convoluted sentences; the complexity of academic

thought is shrugged off as elitist obfuscation. Legislatures and businesses call on higher education to focus on what matters to them, such as training students to be future workers and entrepreneurs. Connecting academic work with community work can effectively counter some of those concerns by making visible the usefulness of fields that aren't readily seen as "pragmatic." And indeed, many students value service-learning courses precisely because of the connections they can make between academic content and the "real world."

To break down this conceptual division between "academic" and "public" work, service-learning helps extend the definition of "public work." Often we talk about "public" life as that which happens outside of the university; we profess that what we are teaching "in here" can better serve students and communities when they work "out there." But I think we present a disingenuous view of the relationship between academic and public life when we treat the two as so completely separate. If we reflect more fully on the intersections of these arenas and use that overlap, we will help our students understand that they can draw on a similar set of intellectual, community-building tools to navigate both worlds.

A longitudinal study of students at Harvard University reveals that when students viewed their writing and research projects as activities with a purpose beyond the specific class, they grew more as writers and felt more engaged with their studies (Sommers and Salz 2004). Students were more receptive to feedback and more engaged in their work. My approach to service-learning tries to harness this motivation and to provide a framework through which students can look at work both inside and outside the academy and see how it draws on similar rhetorical approaches and meets similar needs. The goal is to teach academic writing in such a way that students recognize it as public work.

In this paper I first offer a precautionary story about setting up service-learning partnerships: I argue that professors need to pay special attention to what communities can teach us. Then I explain the common rhetorical features of academic articles and the publications of community organizations: both scholars and community organizations draw on rhetorical strategies to build their public support. Both work hard to convince their audiences that their methods of making and sharing knowledge are valuable. Both make implicit arguments about what is worth paying attention to, what an audience should do, and how people in the audience are connected to each other. After briefly explaining these rhetorical strategies, I will show how they appear in both a community document (a "report card" compiled by two local environmental organizations about the state of the Anacostia River) and a scholarly article (a chemistry article that studies how PCBs flow down the Anacostia River). Because students in service-learning

courses are surrounded by both academic and public ways of working, talking, and writing, they have an opportunity to study how people indicate these underlying values within both kinds of writing. When service-learning professors show students this overlap, we not only prepare them for writing in both places, but we also give them tools to analyze and reflect on the values that are inherent in the writing they may be asked to do in either place. We can show them how to move back and forth successfully and with integrity.

Epistemological Questions: Who makes knowledge and how?

The term "service-learning" designates many different relationships between classrooms and communities. Sometimes students perform direct service with a community organization (serving as tutors for an after-school program, for example, or serving food at a shelter). Sometimes students take on research and writing tasks commissioned by an organization (conducting community surveys about health issues or local development; creating marketing materials or researching best practices). Sometimes students work individually; sometimes the whole class takes on a project together. In this article, I work with a model in which students conduct research (either individually or collaboratively) on behalf of the organization. This research may be commissioned by the organization, or it may be developed in response to a need that the student identifies after working at the site. This model of service-learning, sometimes called community-based research, requires the student to collaborate closely with the community organization to identify parameters, understand local context, and gain access to community resources.[i]

If we and our students enter into a commitment to produce research for or with a community organization, that community relationship must be approached mindfully. In particular, we need to be careful about how we understand what counts as "knowledge." The tension between academic and community knowledge is constant. Faculty and students have the luxury of time and resources to conduct research that nonprofit staff may not be able to carry out, but members of community organizations have a much fuller understanding of the context and history that will affect what knowledge is useful and appropriate to their settings. As we design service-learning courses, we can include units that investigate how community organizations draw on academic scholarship in developing and carrying out their programs, and units that examine where academic scholarship is supplemented—or even corrected—by knowledge-on-the-ground. We should regularly emphasize the question of who makes knowledge and how? What kind of knowledge is valued where? What is knowledge supposed to do? What responsibilities and obligations do knowledge-makers have?

Understanding the relationship between academic perspectives and community perspectives requires careful listening and preparation. When I first started teaching service-learning courses, I made the mistake of organizing my course around academic theories that I expected would be illustrated through the community work my students were engaged in. My course drew on theories of participatory democracy and rhetorics of social protest; we investigated the qualities of direct democracy and how citizens might be empowered to rally for change. Our readings were about grassroots democracy that pressured government for policy and funding changes. The community organizations I worked with, though, drew on different models of social change: they developed on-going, measurable projects that might transform a neighborhood slowly. They developed after-school tutoring programs for middle school students; they brought people together to clear hiking trails and plant gardens. Because of the design of my course, my students left the semester feeling as if these community organizations were adequate but not particularly important. They didn't see community organizations as vital to democratic life. As a teacher, I had to pause and reconsider. Instead of beginning with academic theories, I had to begin with the community organizations themselves and understand that democratic vision, which I then built into my course. Whereas my first course design reinforced the hierarchy of the academy judging the community, my second course design began by assuming the community had the knowledge and the theory. Through my class, the students and I worked to understand their perspective and integrate it with the academic literature. At the same time, we came to see how community perspectives pushed and challenged academic scholarship.

Another misfire offers a second cautionary reminder. The activities we develop together and the way we prepare our students to enter into those partnerships need to attend to the particular historical and contemporary tensions in a place. David Coogan (2006) describes a service-learning writing class that was invited to help increase parental involvement in Chicago's public schools. He observes that the class chose an ineffective rhetorical approach because they had not attended carefully enough to the historical dynamics of the community's experiences. They had not understood what kind of change the parents felt was possible. What Coogan's example makes clear is that all public work is contested work: all communities struggle to define who they are and how they come together.

The admonition to pay attention to local context applies to service-learning partnerships in all academic fields: chemistry students working with environmental organizations to study waterways, education students working with

tutoring programs to boost academic achievement--we all must prepare for our partnerships by understanding how past government, community, and cultural dynamics might affect the work we undertake. At the same time, we must consider how the context of the university, with its own agendas and epistemological ideals, impacts the relationships. Making all of these components visible to students is an exciting and important aspect of service-learning courses.

Rhetorical Moves of Public Making

Mindful of my admonition to learn from the communities we work with, I want to show that analyzing public writing can help us see academic writing in new ways. Because the methods and audiences for academic writing can be so specialized, it's easy to assume that academic writing is distinct and isolated from any writing that would be used in community organizations. An academic paper that analyzes how specific chemicals flow down a river is a very different sort of document than a brochure from a community organization working to clean up that river is. However, the chemistry article, like the brochure, is a response to a particular rhetorical situation. Neither the article nor the brochure is a simple transcription of fact. Just as the brochure is crafted to draw on the values of its local audience, the academic article is carefully crafted to demonstrate the author's understanding and affirmation of the values of the academic community. Both authors have to persuade their audiences that what they say is important and worth reading, that the author is the most qualified person to learn from, and that the author has taken into account the values and expectations of that audience. Moreover, both texts project how the audience is expected to advance this work, to continue what it takes to find the answers to the problem posed. In this sense, academic writing is a form of public writing.[ii]

I find that I can better name and explain these rhetorical strategies when my students and I begin by looking at public writing, especially the documents produced by nonprofit community organizations. Community organizations make their mission and vision very explicit; in websites and pamphlets, we can readily see overt statements about their purpose and methods. Moreover, it's easy for students to understand why community organizations need to regularly convey their worldview—their sense of how the world is and how it should be—and why community organizations need to assert that they have the capacity and the right methods for getting to that vision. Beginning with community documents, we can then begin to see the similar rhetorical strategies in academic work.

We can break down the public-making strategies by looking at several components of public writing: purpose (what creates the need for this work?),

agency and capacity (who can do the work?), and interdependence (with whom do they do this work?). Looking at each of these components of writing can help us uncover the worldview that the text is advancing. I offer a brief glossary of these concepts here.

Purpose: Community organizations and academics alike have to signal the reasons for doing this work in this place at this time; in so doing, they delineate what they see as possible and why it matters. Community organizations are explicit about their purpose in mission statements; these are often incorporated into their publications in some way. Those mission statements define the problem or ideals that motivate them (sometimes emphasizing the urgency of a bad condition, sometimes highlighting a vision they strive toward). All of the documents that the community organization produces flow from this mission and vision.

At the university, the mission and vision is not made quite so explicit. Some college departments and universities publicize their mission statements, and these ideals might be conveyed in strategic plans or Presidential addresses. If we consider that the most frequent publications of universities are academic articles and books, a value built into universities when such publication is a requirement for tenure or promotion, then the purpose for university work is to create new knowledge. In academic articles, we find, the "problem" being addressed is a gap in knowledge, a misunderstanding of how the world works. Academic writing is motivated by a need to correct or advance what has come before.

In both communities, the purpose for writing is defined in such a manner that it suggests who can do the work and what actions need to take place.

Agency and Capacity: One of the most critical steps in bringing people together as a public who will take action together is to convince the audience that they are the ones who can do the work, and that they have the right tools to do so. Nonprofit organizations might define agency and capacity in various ways. Sometimes they highlight civic power (the importance of voting and monitoring the public policy decisions of those in power); sometimes they highlight consumer power (boycotting, pressuring corporations to change their behaviors); sometimes they highlight do-it-yourself community power (such as removing trash from a river, creating after-school programs, or putting on a community fair).

Academics locate their agency and capacity within their disciplinary research methods, methods designed to ensure objective and thorough analysis. The author convinces the audience that the methods are appropriate for this

particular question under review. At the same time, the author invites researchers to continue to investigate the problem and the methods for answering it. In providing an answer to the gap in knowledge, the researcher contributes to an ongoing scholarly conversation, and invites further reflection on the methods or the outcomes of the research. In this way, academic writing perpetuates its own vision of what matters: it perpetually demands that scholars create new, more, better knowledge. Just as a community document rallies its audience to take specific action, so the scholarly article serves to motivate and extend the work of the academy.

Interdependence: Public writing speaks to multiple audiences: it addresses individuals who are part of a broader public, equally invested in the issue at hand. It has to signal to the reader that he or she is part of that larger group and that by working together, the reader can accomplish more than he or she can individually. The rhetorical strategy that accomplishes this is to address both friends and strangers simultaneously. One might name leaders and associations that are part of the cause already and also name concrete opportunities for new people to get involved. One might describe people currently in the community who have similar values or experiences as those who have not yet joined, so that they can see themselves already there.

In academic writing, the audience is an academic public that is committed to creating knowledge together over the long term. As Joseph Harris (2006) explains convincingly in *Rewriting: How to Do Things with Texts,* academics draw on the works of those who have come before by extending their ideas, countering their findings, or drawing on their methodology. Especially in the review of literature sections, but often throughout the analysis, academics name colleagues working on the same kinds of questions. These moves demonstrate that knowledge-making is clearly a collaborative enterprise. Indeed, all the rules for accurate and complete citation are in place to ensure that the collaborative motive is not compromised by sloppy or unethical attribution. They are tools that academics use to reinforce and perpetuate their interdependence; they signal that no individual scholar can arrive at a full, complex view of the world—we need each other.

Faculty teaching service-learning courses can help students understand how writers invoke the public value of their work for both community and academic contexts. The framework helps us to the common rhetorical strategies in academic and community work. Moreover, examining these strategies can help us name the aspects of service-learning that can be difficult. Sometimes, the conventions that ensure that one's place in the academic public can be at odds

with the conventions of the communities where we work and vice-versa. Students need to pay critical attention to the distinctions among those conventions if they hope to cross boundaries effectively.

Anacostia Watershed Society and the George Mason University Chemistry Department: A Study in Public and Academic Writing

The service-learning context can offer helpful, specific ways to explicate these rather abstract concepts. Using concrete examples, such as websites and reports, we can compare the rhetoric of academics and community organizations and show how those moments in the texts that convey purpose, capacity, agency and interdependence also convey the underlying value systems within each group. To illustrate, I'll offer a case study of the Anacostia Watershed Society in Washington, DC, their *State of the River* report, and a study about polychlorinated biphenyls (PCBs) in the Anacostia River conducted by George Mason University chemistry professors and published in the *Journal of Environmental Science and Health.*

Overview of the river and the two communities who report about it

The Anacostia River flows through the eastern Washington, DC, bordered by Wards 5, 6, 7 and 8. It is fed by watersheds in Maryland's Montgomery and Prince George's Counties. Near the southern tip of DC, it feeds into the Potomac; then it joins the Chesapeake Bay and drains into the Atlantic. The Department of Health of Washington bans any recreation that would provide primary contact with the river, and it has declared the fish and shellfish too contaminated to eat. The pollution in the river has been attributed to overflow from DC sewage treatment centers during storms, other DC and area stormwater drainage problems, agricultural chemicals flowing down from Maryland farmlands, and pollution and leaks from industries and or contaminated sites of now defunct industries.

One community organization that would like to see the river clean is the Anacostia Watershed Society (AWS). The mission of The Anacostia Watershed Society is "to protect and restore the Anacostia River and its watershed communities by cleaning the water, recovering the shores, and honoring the heritage in order to make the Anacostia River and its tributaries swimmable and fishable for the health and enjoyment of everyone in the community." The organization maintains on-going partnerships with area universities, and students are invited to help with trash clean-up and removal of invasive plants. AWS partners with local science classes at all levels, as well as with local

environmentally-oriented community organizations. They focus on recreational activities (to help people develop a familiarity with and commitment to the river), stewardship activities (removing non-native plants, picking up trash, building rain gardens, monitoring water quality) and advocacy work (identifying sources of pollution and applying pressure on appropriate targets to address them).

An academic researcher who studies the pollution in the Anacostia River is professor of chemistry and biochemistry at George Mason University, Dr. Greg Foster. Like the AWS, the goals of the Foster laboratory include tracking down sources of contaminants and aiding in river clean-up. The GMU chemistry and biochemistry department announces that students working with Dr. Foster can expect to contribute to projects along the Anacostia River:

> Students in the Foster research laboratory investigate the sources, reactions and transport of contaminants in the aquatic environment. [One of the] ongoing lines of active research . . . involves determining the amounts and sources of polychlorinated biphenyls (PCBs) in storm runoff in the Anacostia River.

In addition to the concrete tasks of identifying pollutants and identifying best practices for removing them, Dr. Foster contributes to the field of chemistry and biochemistry by developing analytical methods. A biographical blurb on George Mason's Research Groups page describes Foster's agenda this way: "divided among assessing urban regions as sources of organic contaminants to coastal air- and watersheds in the Chesapeake Bay region, developing technologies to remove contaminants that harm the aquatic environment, and developing analytical methods."

This last point is a critical distinction, as it indicates Dr. Foster's commitment to the university as a place to develop and refine research methods. Whereas the AWS hires chemists and biologists to monitor and track the impact of pollutants, Dr. Foster's purpose is also to evaluate and improve the methodology used to do such work. In this way, his affiliation to the university, and to the broader goals of knowledge creation, exceeds the practical focus on cleaning up the river.

Analyzing Community and Academic Documents about the Anacostia River

To illustrate how scholars and community members build a sense of public purpose and capacity in their writing, we can compare the *State of the River Report Card*, a publication from the Anacostia Watershed Society, with an

article co-written by Dr. Foster in the *Journal of Environmental Science and Health* that also evaluates pollution in the Anacostia River.

The *State of the River Report Card* is an 8-page 8 ½ x 11 glossy pamphlet with a full color photo of a Great White Egret and a Great Blue Heron standing in the Anacostia River. Most of the pages include large graphics and little text. The first page offers a short welcome statement from the President of the Anacostia Watershed Society and the Riverkeeper and Executive Director of the Anacostia Riverkeeper (AR), the organizations that jointly wrote the report. They explain, "This annual report card is your guide to how well our communities, environmental groups, and governments are meeting the goal of a fishable and swimmable Anacostia River as soon as possible. …. It provides a benchmark of the core river health parameters based on scientific data and policy efforts" (p. 1). Below the letter, but above the signatures, is a photo of the two leaders, standing in front of the Anacostia River. The mission statements of the two organizations are listed. At the bottom of the page, in small print, is a series of "disclaimers": these footnotes report the assumptions behind their methodology, with acknowledgements like, "All available, professionally collected data was used. The data sets include those collected by DC government, Maryland Department of Natural Resources, and the Anacostia Watershed Society." Acronyms are explained, and explanations about rate calculations are provided.

The remaining pages lay out the findings, using short paragraphs and plenty of graphics. The second page shows a map of the Anacostia River with named bridges indicated. Three large "Fail" notations are stamped along the river. The page defines the three main areas studied and the main impediments to clean water, and the parameters used to assess the water quality. The third page includes a chart, delineating the water quality according to each of the assessment areas and the number of years estimated to meet the water quality standards. Page four is a political report card, evaluating public policy around stormwater management, toxics, trash and overall plan for DC, two Maryland counties, the State of Maryland and the Federal government. The ratings are indicated visually by thumb-up or thumb-down hands. The final pages provide brief (one-to-two phrase) explanations of the problems that the river associations seek to address, with photographs and one or two sentences describing solutions, which include environmental site design (such as rain gardens) along with political pressure and legal action to address trash, toxics and bacteria.

The *Journal of Environmental Science and Health* article, in contrast, is a dense seven and a half page document followed by a page and a half of footnotes. The descriptive title is "Polychlorinated biphenyls in stormwater runoff entering

the tidal Anacostia River, Washington, DC, through small urban catchments and combined sewer outfalls." The abstract announces that the major findings contradict previous assumptions about the primary sources of PCB contamination: "The present study suggests that input of PCBs from Lower Beaverdam Creek is likely to be greater than those from the two major branches (Northeast and Northwest Branches) that were believed as primary source areas."

The article includes an introduction, which reviews the current state of the Anacostia River, drawing primarily on government reports and identifying the exigency for this project: "To achieve the first goal of the Anacostia River action plan—the reduction of pollutant loadings—it is essential to understand the sources and behavior of pollutants in stormwater runoff, which is regarded as one of the major pathways delivering urban pollutants to surface water" (p. 568). The paper argues for the necessary methodology to complete such a task, "A quantitative understanding of the sources of PCBs in stormwater runoff and its transport dynamics in the Anacostia River will be essential in developing cost-effective stormwater runoff control strategies employing effective best management practices" (p. 568).

After reviewing the sample collection and the strategies and materials used for extracting PCBs, the majority of the article discusses the level of PCBs in stormwater runoff, noting that most occur as particles, and then evaluating how the particles behave in the water. The analysis includes explanations about the techniques used to evaluate the data, equations that express the relationships of materials in the stormwater, graphs that show the linear regressions of some findings. The analysis refers frequently to the previous studies of PCBs in the Anacostia River and elsewhere, both to give credit when this study uses their techniques and to indicate how the current study extends the findings or methods of those works. It concludes with a review of the findings, acknowledgements of the funding sources for the research, and thirty-five bibliographic endnotes.

Purpose: Both documents arise from a concern about pollution in the Anacostia River. The *State of the River* responds to a political need to document progress (or lack of progress) from DC, Maryland counties, Maryland state and federal agencies in stemming the causes or cleaning up the pollution. It provides a water quality report that looks at four indicators of pollution; by highlighting the number of years until the water quality will meet set standards, it again heightens the need to take action. The document is created to rally people to take action and to encourage them to take action with AWS and AR.

Identifying the purpose in academic work can be harder for students, who often criticize academic work for merely explaining problems and not laying out

solutions. The scholarly article is also motivated by a concern about pollution in the Anacostia River and it draws on government sources to clarify the urgency of the problem. The main focus of the article, though, is not the lack of progress but a gap in the understanding of the problem itself. The goal is not to rally people to make change, but to rally people to study the problem more closely so the action later on taken will be most effective. The article seeks to "understand the sources and behaviors of pollutants in stormwater runoff," and while the ending does suggest some potential best practices to address the sources and behaviors that the researchers found, the majority of the document lays out the methods and analysis that allow them to better describe one particular part of the problem. The article is designed to build on previous research and provide evidence-based data that can contribute to someone else's solution design.

Agency and Capacity: We can readily see how the authors of the *State of the River* indicate that they have the capacity to take on the problems they've identified. The introductory letter from the Executive Director of Anacostia Riverkeeper and the President of Anacostia Watershed Society ends with an upbeat assertion that "We can clean [the River] up if we work together!" After listing the current failed water quality standards and lack of action by the politicians, the document outlines the solutions that the nonprofits advance to address the issues. The problems are depicted visually with photographs of the river. For the problem "Stormwater," we see a photo of the River under normal flow and a photo of the same site with high and turbulent waters. The solution is "Environmental Site Design," such as raingardens that "maintain a site's original drainage pattern as much as possible by capturing and infiltrating rainwater." Similarly, the page on the problem of "Toxics, Trash and Bacteria" uses a photograph of trash in the water and a picture of an industrial building tagged as a "legacy toxic site." Here, the solution is "education, restoration projects, and legal action." Finally, the document lists the eight actions individuals can take, including supporting the organizations by donating and volunteering. The reader of the document is invoked as someone who has power to pressure the political entities who received the thumbs-down ratings, and who can support the work of the organization through donations, volunteering, and a few individual actions.

Finding the indicators of agency and capacity in the academic article is easier when students understand the audience to be other academics, whose job is to scrutinize the methodology and analysis of any study. As Frank Haig and Peg Kay argue in "The Role of Academies of Science in the Critical Examination of New Ideas," professional communities "provide a willing but intelligent audience to which an innovator can make a presentation" (p. 61). Once presented, "a new

idea has to find its way to acceptance. The path may be long and conflicted. The opposition may be intense and tortuous. The process, however, is necessary to ensure the emergence of a founded confidence on the part of the broad scientific community" (p. 61).

Once we understand this context, it's easy to find the places where the PCB report authors assert who has the capacity "to understand the sources and behavior of pollutants in stormwater runoff" (p. 568). Throughout the article, the authors anticipate their skeptical audience by reaffirming the capacity of their disciplinary and interdisciplinary methodology to explain pollutant sources and behaviors. They regularly anticipate concerns about how they have executed the techniques, acknowledging and justifying whenever they have made variations on previous methods. Moreover, they regularly qualify their assertions; they understand that for their argument to be persuasive, it cannot exceed the capacity of the methods. In this way, they provide an active and important role for their academic readers, just as AWS and AR do for their civic readers.

Interdependence: Examining the rhetoric of interdependence in a document can help us gain a deeper understanding of how the authors imagine the members of their audience should relate to each other to accomplish the work at hand. The nonprofit authors of the *State of the River* depend on public attention and action to achieve their political and environmental goals, so their readers must come away from the document feeling as if they are part of a broader community that is invested in the cause. The rhetorical challenge in such a document is to address newcomers and current participants at the same time, and to help them see their relationship with each other. Some of the gestures that invoke such interdependence are easy to spot—as in the closing of the introductory letter, "we can clean it up if we work together! Will you join us?" The audience here is the newcomer, interested in becoming part of the "us" crowd. The solutions proposed are described as "our" solutions and what "we" do. However, sometimes the reader is treated as separate from the organizations, a move that seems to undermine the message of interdependence. The organizations are given agency and capacity for certain kinds of change, while the reader is invited to take different steps. The steps that "you" can take include actions readers can do individually, without the nonprofits. While the final action is "support the Anacostia Riverkeeper and the Anacostia Watershed Society," the overall phrasing in this section suggests that the reader may not need the organization in order to accomplish the same goals.

Just as public texts should convince their audiences that they are already potential actors in that community, so in academic context, the readers should see

that they have a significant, important role in the broader goal of knowledge-making. Through the exchange of scholarly articles, scholars depend on each other to help create, critique and extend knowledge. The bigger goal of arriving at new understanding does not happen alone, and scholars regularly and explicitly acknowledge their dependence on other scholars throughout their work. We can see these efforts throughout the PCB article, as the authors name those scholars who have asked similar questions in other geographical areas: "For comparison with the present study, some other studies are summarized below" (p. 570). They also confirm their results by comparing them with similar studies: "This high enrichment of PCBs in the particle phase is quite common in urban stormwater samples. Eganhouse and Sheerblom found high concentrations of PCBs in the particle phase (50-98%) in combined sewer overflow samples" (p. 570). The general academic habits of citation and attribution are part and parcel of this need to acknowledge interdependence. By acknowledging how our methods and analysis have been influenced by previous scholars, we signal that we understand that on-going knowledge requires us to read each other critically, to explain the heritage of our ideas, and to offer a clear roadmap for future scholars so that they can replicate our work. If we skip any of these steps, we risk violating the expectations for our roles as members of the academic community.

Public and Academic Writing in Service-Learning classes

To keep my argument relatively concise and straightforward, I limited my analysis to two documents related to the same public concern. When faculty develop partnerships with community organizations working on public issues, and when we help students conceptualize research projects that can be useful to those organizations, I suggest that we ask students to prepare both academic- and community-orientated documents based on their research. The challenge of transforming their analysis to meet the different expectations of each community allows them to explore the parallels and distinctions in those rhetorical conventions. I further contend that we provide a helpful framework for understanding the variations they find. A productive rhetorical framework will demonstrate that at a broader level, academics regularly signal their participation in academic communities as they write, and they follow conventions that reveal their understanding of what academics value and their understanding about why academia itself is valuable to the broader public. To accomplish this, academics project their purpose, their agency, their capacity to address the problem, and the audience's interdependence with the author and each other. By comparing the rhetoric of community organizations with the rhetoric of academia, students in service-learning courses can see that both groups draw on a repertoire of

community-building strategies. Naming and analyzing these distinctions can help students consider their own responsibilities and potential as "academic citizens."

References

Anacostia Riverkeeper and Anacostia Watershed Society (2010). *State of the River Report.* Washington, D.C.: Author.

Coogan, D. (Jun 2006). Service learning and social change: the case for materialist rhetoric. *College Composition and Communication, 57*(4), 667-693.

Corporation for National and Community Service. (2007). *The impact of service-learning: A review of current research.* New York: Author.

Deans, T. (2000). *Writing partnerships: Service-learning in composition.* Urbana, Ill.: National Council of Teachers of English.

Eyler, J. S., Giles, D. E., Jr., & Braxton, J. (1997). The Impact of Service-Learning on College Students. *Michigan Journal of Community Service Learning,* 4, 5-15.

Haig, F. R., and Kay, P. (2006). The role of academies of science in the critical examination of new ideas: looking at Gaia. *Journal of the Washington Academy of Sciences Summer,* 61-67.

Harris, J. (2006). *Rewriting: How to do Things with Texts.* Logan, Utah: Utah State University Press.

Hauser, G. A. (1999). *Vernacular voices: The rhetoric of publics and public spheres.* Columbia: University of South Carolina Press.

Hwang, H., and Foster, G. D. (2008). Polychlorinated biphenyls in stormwater runoff entering the tidal Anacostia River, Washington, DC, through small urban catchments and combined sewer outfalls. *Journal of Environmental Science and Health Part A, 43*, 567-575. doi:10.1080/10934520801893527

Ryder, P. M. (2011). *Rhetorics for community action: Public writing and writing publics.* Lanham, Md.: Lexington Books.

Sommers, N., and Saltz, L. (2004). The novice as expert: Writing the freshman year. *College Composition and Communication, 56*(1), pp. 124-149.

Warner, M. (2005). *Publics and counterpublics.* Cambridge: Zone Books.

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[i] In *Writing Partnerships*, Thomas Deans offers a helpful overview and useful advice about "writing for" and "writing with" communities in service-learning courses.

[ii] For more on theories of public rhetoric, see Hauser, Ryder, Warner. For more analysis of the public function of the academy, see the final chapter in Ryder.

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Service-Learning in Croatia and the region: progress, obstacles and solutions

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Abstract

The goal of the paper is to discuss the possibilities of transforming universities in Croatia and the region into places that take account of the emerging community trends and current challenges that our students should be capable of dealing with once they finish their studies. Service-learning (SL) was introduced in the largest faculty of the University of Zagreb (Faculty of Humanities and Social Sciences) in 2006-07 through a series of faculty workshops and through academic courses. The goals and requirements of this teaching and learning method were based upon our U.S. experience, gained at the George Washington University. Since then around 50 SL projects in the IT field have been completed and evaluated. Service learning was also introduced in the Faculty of Economy at the University of Rijeka in 2008. In 2009 it was added as a regulation of the Croatian National Youth program 2009-2013, approved by the Croatian Government. Also, in the same year the Croatian translation of the term "service-learning" ("drustveno korisno ucenje") offered by the author of this paper became accepted as a common term at the JFDP (Junior Faculty Development Program) Regional Conference. Although the workshops were extremely popular both in Croatia and the region, and although SL courses achieved remarkable student enrollment in a short time, the number of faculty who have so far implemented it as a teaching strategy is very low. This paper discusses the reasons for faculty resistance to engage in SL and some possible solutions.

Introduction

In this paper we present the recent development and evaluation of service-learning (SL) in Croatia and the region, explaining the advantages and drawbacks of the application of SL in the Bologna Process in our universities.

The Bologna Process is a European reform process driven by the 46 countries aiming at establishing a European Higher Education Area (EHEA). The Process officially started in 1999, when 29 countries signed the Declaration in Bologna (hence the name of the whole Process). The Declaration states the following objectives: adoption of a system of easily comparable degrees based on two main cycles, undergraduate and

graduate; establishment of a system of credits – European Credit Transfer System (ECTS) and promotion of European co-operation in quality assurance.

Croatia joined the Bologna Process in 2001, in Prague, where the ministers adopted the so-called Prague Communiqué, introducing several new elements in the Process: students were recognized as full and equal partners in the decision making process; the social dimension of the Process was stressed and the idea that higher education is a public good and a public responsibility was highlighted.

The purpose of this paper is threefold. The introductory part gives an overview of the most important problems facing higher education in Croatia today and presents a remarkable solution to these problems – service-learning. The second part identifies the problem of integration of service-learning in the curriculum and provides suggestions to advance service-learning in Croatia and to improve student confidence and knowledge of the world by combining service learning and e-learning teaching methods. Finally, the third part of the paper describes the progress of service-learning in Croatia and the benefits it brings to students and the whole educational system.

Challenges to the Croatian Educational System

The two most important educational issues facing higher education in Croatia and the region[i] today are: theoretical knowledge without skills and a weak connection between the university and the community and between the university and the labor market. Higher Education (HE) institutions in Croatia and the neighboring countries have worked for many years on their curriculum to keep pace with the scientific advancement of the field. The community, on the other hand, has its own development, emerging trends and problems that our students should be capable of dealing with once they finish their studies. The development of community, labor market and HE institutions each has taken a different track.

The London Communiqué, with the working title *Towards the European Higher Education Area: Responding to Challenges in a Globalized World* is a document of the Ministers of Higher Education in the countries participating in the Bologna Process. It reviews the progress made in their countries since meeting in Bergen in 2005. The ministers emphasized the need for an attractive and competitive labor market in Europe and pointed out the major problems faced by higher education

institutions: preparing students to become active citizens in a democratic society, as well as preparing them for their constantly changing future careers, enabling their personal development and stimulating research and innovation.

All the above mentioned issues are far more complex in Southeast Europe than they appear to be in other European countries. A detailed insight into those educational issues in Croatia results from a survey[ii] on the implementation of the Bologna Process carried out at 5 Universities in Croatia (University of Zagreb, University of Rijeka, University of Zadar, University of Split and JJ Strossmayer University of Osijek). The survey involved a total of 3261 students in their second year of study.

We learned from the survey that 40% of the students study only to pass the exams at the end of the course, not to acquire knowledge and more than 50% of them never engaged in class discussion (either because they never had a chance for it or because they do not feel comfortable expressing their opinions in front of the large class). For one third of the students (31%) the biggest problem is low level or almost no practical work. Many lecturers think that an academic institution is not a place where students should get knowledge at the application level, but rather on a more abstract, theoretical level. Therefore, the majority of them emphasize lecturing and theory rather than application and discussion, and it is not a rare case that a law student never visits a court or that a language teacher never tries teaching a class before he or she gets the diploma.

One of the changes that the Bologna Process initiated was interactive teaching and focusing more on student's skills, competences and the practical implications of course material. The most frequently mentioned student expectations of the Bologna Process in Croatia, which unfortunately have not been fulfilled to date, are: work in small groups, teamwork, fieldwork and practical classes. In addition, the results of the Gallup survey (European Commission: Eurobarometer, 2009) revealed that 76% of Croatian students strongly agree that they need more opportunities to acquire skills to meet the demands of today's workplace - communication skills, teamwork and learning to learn. Also, 66% of higher education students in Croatia strongly agree that study programs should focus on teaching specialized knowledge. Finally, between 70%-78% of students in Croatia also said enhanced personal development was a very important goal of higher education. The survey's fieldwork was carried out from 12 February to 20 February 2009. Almost 15,000 randomly-selected students in higher education institutions were

interviewed in the 27 Member States of the EU, Croatia, Iceland, Norway and Turkey.

Regarding opportunities to find a job after getting a degree, most of the students in Croatia do not have confidence in the current educational system. The biggest and justified concern our students have is linked to the weak connection between the labor market and HE. The fact is that at the moment there are 315,438 unemployed people in Croatia (an unemployment rate of 18.7%).[iii] This is one of the largest obstacles for the country's development. Unemployment continues to grow annually, with a strong increase among highly-skilled laborers, limiting the competitiveness of the domestic economy and economic recovery. These are the most important problems facing higher education in Croatia today. These issues should be targets for further research and development of the Croatian Higher Education System.

Service-Learning: A Strategy for the Croatian Educational System

This paper proposes service-learning teaching and strategy as a way to address these community and educational challenges. The approach emphasizes the integration of service learning into the curriculum in Southeast Europe and Croatia in particular.

Service-learning (SL), a teaching strategy that integrates meaningful community service with academic learning, is a remarkable solution for bringing community, labor market and HE institutions in Croatia and the region more closely together to satisfy the goals of the Bologna Process.

Through service-learning our students could learn not only how to connect course theory and practice, but also how to help others, give of themselves, and enter into caring relationships with others in their community. The goal of service-learning is to assist students to see the relevance of their new knowledge in the real world. That is what they are missing at the moment.

Although well developed in North America, SL is for the most part still absent in Europe. The Community Learning Program that has been developing since 2001 in the Dublin Institute of Technology was, until recently, the only European example of service learning.

Service-learning was introduced in the final year of graduate study in the Faculty of Humanities and Social Sciences, the largest faculty of the University of Zagreb (Croatia), in 2006-07 through a series of faculty

workshops and academic courses. The goals and requirements for this teaching and learning method were based upon my U.S. experience gained at the George Washington University, where I was a Junior Faculty Development Program scholar.

Up to that point, students of information sciences learned the theoretical concepts and applied them to imaginary or simulated circumstances, but rarely managed to apply the acquired knowledge to the real world. The service-learning projects provided them with structured time to rethink and implement ideas that they had during their 5-year study, but never had an opportunity to transform them into "hands-on" experiences and observe the results.

In the first two years, about 50 SL projects in the IT field were completed and evaluated (Mikelic Preradovic, Kisicek & Boras, 2010).

After the successful project outcomes in the test phase, service-learning was introduced into the final year of undergraduate study as well, as a part of a new curriculum under the Bologna Process in the Academic Year 2007-2008. Students were surveyed at the end of that academic year and the results showed that such placement in real (vs. theoretical) learning situations was very important in increasing the confidence and self-esteem they felt they needed once they entered the labor market. These projects will serve as an excellent reference and indication of their creativity and ability to engage intellectually, emotionally and socially.

Regarding the unemployment issue, we believe that an innovative framework to addressing high-skilled youth unemployment would be to combine service-learning, community development, and career development into SL projects that would increase student's levels of personal and social development, core skills and employability and build life-long connections between students and their communities.

Service-learning can assist our students with developing work/life skills, knowledge and career passions which could improve their future work prospects through increased community awareness. Furthermore, it can increase their ability to develop and match specific and transferable skills with the requirements of today's labour market. Finally, service-learning can help (at least as a partial solution) to meet the educational needs of long-term unemployed people and to develop learning opportunities in response to identified need.

Despite the obvious benefits SL brings to students and the whole educational system, it is not yet popular among the faculty in Croatia and

the region, at least not as popular as e-learning.[iv] In the next part we offer potential explanations and examine how we might overcome the barriers to the adoption of service-learning in Croatia and Southeast Europe.

Service-Learning: Challenges to Integration in Croatia

With so many obvious benefits, one might think that faculty members in Croatia would universally embrace service-learning with great enthusiasm. Unfortunately, that is not the case.

Although the service-learning workshops in Croatia were extremely popular and received strong support from the Dean in the Faculty of Humanities and Social Sciences, the number of faculty who have since implemented SL as a teaching strategy is very low.

Perhaps the reasons for this can be found in the workshop exit surveys. When asked if they plan on incorporating SL into their teaching, a certain number of attendants expressed worry that this teaching strategy is more time-consuming and requires more devotion than traditional seminar teaching. They also mentioned logistical difficulties in implementing SL, since their class is usually big and it is hard to organize students in groups with similar levels of motivation that will work productively at the same pace.

Regarding the logistics, teaching loads in Croatia are really heavy. By way of comparison, a single bachelor course at the Faculty of Philosophy, University of Zagreb has 60 students enrolled every year on average, while for the same course at Georgetown University in Washington, DC, there are up to 10 students enrolled per year.

Apart from the SL issues, another issue is that our faculty teachers lack autonomy in curriculum design. The Croatian Ministry of Science, Education and Sports designs the curriculum and dictates what shall be taught and, unfortunately, the faculty members have a relatively minor role in that process. Consequently, faculty teachers have less freedom to innovate in their teaching, but also little tradition and motivation to innovate.

Although integration of service-learning into curricula affects Eastern European areas on a larger scale, the problem is not geographically limited. Although perceived as a successful and innovative teaching strategy by many practitioners in the field (Strand, Marullo, Cutforth, Stoecker & Donohue, 2003; Marullo & Edwards, 2000; Bringle, Games, & Malloy, 1999), barriers against its integration in the U.S.

curriculum include: scarce administrative support, faculty participation, and budgetary constraints (Bringle & Hatcher, 2000; Holland, 1997; Ward, 1996).

We posit that the above mentioned reasons are not strong enough for Croatian faculty to avoid engagement in SL projects and teaching strategy on such a large scale and that they only need an excellent enticement to recognize service-learning as a research and teaching tool worth the time and the effort.

Our five-year service-learning research and experience shows that faculty who replace the seminar part of their course with SL projects (in other words: those who replace imaginary problems and solutions with real community experience) never give up this teaching method, no matter how scarce the budget or administrative support may be. On the contrary, they enthusiastically continue to motivate students to enroll and they emphasize that every year it becomes less time-consuming, more meaningful and definitely more than a setting to teach theoretical concepts in a hands-on manner, once they get past the initial logistics.

The obvious benefits of SL for faculty members is taking on new roles, seeing students excited and the classroom energized, building personal connections with students, learning from our students and seeing greater student involvement in discussions and the relevance of the subject. These benefits outweight the logistical problems.

Therefore, we believe that we need to discover the key motivators to raise Croatian faculty's interest in service-learning. We also believe that combining service-learning with new and successful e-learning methods that are still not used in Croatia (such as introduction of e-Portfolios) would make the faculty more willing to engage in SL.

E-portfolios are digitized collections of text-based, graphic, or multimedia artifacts including demonstrations, resources, and accomplishments that represent what a person has learned over time on which he/she has reflected. They are designed for presentation to one or more audiences for a particular rhetorical purpose and can be used for final assessment as well as for reflection, deep learning, knowledge growth and social interaction.

The faculty could first start using e-portfolios as a tool for student reflection in their e-courses; while later it can be employed as a tool for connection of the service experience to learning in their courses.

Therefore, we plan to explore the possibility to connect SL course design with e-course design, so that Croatian faculty members get the opportunity to combine the elements of two educational innovations (e-learning and service-learning) in a thoughtful way.

Service-Learning: Progress in Croatia

During the Academic Year 2006-07 the author conducted workshops for the Croatian faculty in different fields and with different Croatian universities, school teachers and NGO's in order to promote SL and share in-class experiences. Service-learning was also introduced in the Faculty of Economy, University of Rijeka (described in detail in the paper co-authored with Jelenc & Mujevic, 2008). As of 2008-09, a stand-alone elective course "Service-learning in Information Sciences" has been offered to all students in the University of Zagreb, and thus achieved remarkable enrollment in a short time.[v]

In 2009 SL was added as a regulation of the Croatian National Youth program 2009-2013 approved by the Government[vi]. Also, in the same year the Croatian translation of the "service-learning" term ("drustveno korisno ucenje") coined by the author of this paper, became accepted as a common term at the JFDP Regional Conference[vii]. Since 2008 all the service-learning projects in the Faculty of Humanities and Social Sciences are transformed step by step into service e-learning projects, offering faculty and students the ability to apply e-learning technology they adore to service-learning pedagogy through service-learning projects that are (at least partially) conducted online.

Due to the fact that the information technology provides an opportunity for students of information sciences to help community organizations, and since information literacy becomes an important social issue, our students truly have a great field for activity where they can meet different interests and apply specific knowledge and skills.

All of our students who took part in service e-learning projects used email, discussion boards, content management system (Moodle), online journals and Word processor collaboration features for sharing, collecting and organizing their work, as well as their reflection.

Below we briefly describe some of the service e-learning projects that were directly related to a community need. In most of these projects, the students selected the project in consultation with the supervisor in the chosen NGO, school, library or museum.

Project 1. Starting with the school year of 2009-2010, all pupils who complete the fourth grade of grammar school in Croatia take the state graduation exam (based on the Act on Primary and Secondary Education[viii]). The state graduation exam has two parts: mandatory exams in general education subjects such as Croatian language and elective exams in one or more optional subjects, such as Informatics. Our information science students came up with the following project idea - an online demonstration designed as a preparatory step for the state graduation exam covering the complete information and computer science curriculum of the state grammar schools. The students' partner was the National Centre for External Evaluation of Education that creates paper exams for all subjects in the state graduation exam and delivers exam materials to schools.

Our information science students summarized their knowledge and skills in the field of computer and information sciences and created the application in the midst of turbulence caused by the introduction of the state graduation exam. With this project they aimed to gain for their own benefit, connecting the theory learned during the study with new practical experiences while at the same time helping the pupils to achieve at a high level in the state graduation exam.

State Graduation Online Demo Exam in Informatics[ix] consists of 50 multiple-choice questions written in ActionScript3 through collaboration with the National Centre for External Evaluation of Education. It was tested and evaluated by the third grade pupils of Velika Gorica grammar school[x], who will take the state graduation exam at the end of the school year 2011-2012. The evaluation was performed as an online survey that aimed to identify the impact of the student project on grammar school pupils and to discover suggestions that could improve the effectiveness of the exam.

The overall rating of the demo test was high. Regarding the service-learning component, this project contributed to the pupils' preparedness for the state graduation exam in an elective subject, informatics, and offered them an insight into new technology and new ways of knowledge acquiring and its evaluation (such as e-learning and online exams). The questions in the demo exam cover the entire content of the subject of Informatics for the 4-year grammar schools, while the simple but interactive online application enables pupils to take the exam and test their knowledge anytime and anywhere, getting immediate feedback.

Project 2. The aim of the project was to develop the educational corner for the elementary school's web page[xi] that would help the school and its teachers to attract more pupils to visit the web page and learn something new or possibly affirm their knowledge on a familiar topic while browsing through the content and the enjoyable educational activities. Students wanted the pupils to learn in a fun, interesting and different way providing an e-environment where they felt comfortable to learn. Our information science students were given numerous handwritten materials made by the school's pupils during their school year that consisted of anagrams, mental maps, games of logic, quizzes on general knowledge, Croatian language and literature, history, *etc*. Although it took a lot of time and effort to convert these handwritten materials into useful e-activities. students used it as a means to attract pupils. Their basic hypothesis was that e-activities would look more friendly, interesting and engaging to pupils, if their own ideas and materials were implemented in the e-environment.

The educational corner was also intended to motivate the elementary schools' teachers to realize the importance of communication with their pupils using a different medium, an online environment, and to encourage them to put their educational materials online in order to establish better communication and interaction with their pupils. Many teachers embraced this application, while school pupils were excited to find that their handwritten materials were used for something creative and useful.

Project 3. Another group of information science students designed a multimedia project for the NGO "Friends of Animals.". Although a leader in their field in Croatia, the NGO was at the very beginning of IT usage when we first established contact and offered help. They had computers and a website, but didn't possess the knowledge to use IT as a driver for reaching their goals.

Therefore, they were excited about the students' SL project, which aimed to inform the citizens about the vegetarian products available in our stores, encourage them to a healthier lifestyle using vegetarian recipes and to learning about healthy food in an interesting way (via an interactive database and multimedia applications on a CD-ROM). The NGO was happy to promote their products by distributing this CD application in the community for free at an event organized during World Vegetarian Day.

One of our students received a job offer from the NGO for the position of information technology manager.

Project 4. Museology graduate students found that their colleagues and friends visited museums in Zagreb rarely, and also that it is difficult to find funding for promotion of museums at the University in the form of posters and brochures. Therefore, they designed an e-brochure with appealing design, freely accessible on the website of the Faculty for all students who want to discover the world of museums in Zagreb. Their partners were the following institutions: Archaeological Museum, Croatian History Museum, Croatian Natural History Museum, Croatian School Museum, Ethnographic Museum, Museum of Arts and Crafts, Tehnical Museum and Zagreb City Museum. The number of e-brochure monthly visits is growing, especially in the beginning of the academic year, when freshmen explore the faculty website.

Project 5. Another project group consisted of Museology graduate students and information technology students with teacher orientation, who designed a workbook for children to complete during a visit to the Zagreb City Museum and art workshops to help them acquire knowledge in a museum. Their client was the Zagreb City Museum, where they tested and evaluated the workbook with a group of elementary school pupils. Both the pupils and the museum staff rated the workbook as an interesting and useful tool for children, which they can keep as a souvenir from their visit to the museum.

Each of the above project groups met a real social need, applying the theoretical knowledge gained during their studies and acquiring new skills required for activities that they selected due to their interests. Another 45 groups also successfully completed excellent service-learning projects.

In order to perform a student satisfaction analysis, we conducted a survey in 2010 described in detail in the paper co-authored with Kisicek, S. & Boras, D., 2010. The evaluation was performed as an online survey that aimed to identify the impact of SL on our students and to collect suggestions that could improve the effectiveness of the course. The survey consisted of 20 questions that tried to encourage students to critically reflect on their SL experience, but also to reflect on the community partners and the course itself.

Female students were slightly overrepresented in our sample: 71.4% of students taking the survey were female. Interestingly, 57.1% of the students did volunteer work before taking this course, but most of them did not perceive it as worth mentioning in their CV. All students (100%) would recommend the next generation of students to enroll in the

course. Also, all of them think that the SL project was a rewarding experience and that they expanded their existing knowledge and skills. The survey numbers show that the majority of our students are willing to volunteer in the community after the completion of the project (92.9%).

The overall quality of their service-learning experience was rated high, with 85.7% of respondents stating it was excellent or good. Furthemore, 71.4% think their SL experience was more educational than the traditional seminar at the university. In regards to the relationship with the community partner, 92.9% of the students would recommend the community partner to future students.

Regarding the SL project influence on students, 50% of them strongly agree or agree that they understand better the needs and problems in their society, 57.1% strongly agree or agree that they feel responsible for progress in the society, 85.7% of students strongly agree to encourage other students to enroll in the SL course, while 78.6% strongly agree or agree that the social aspect of the project demonstrated how they can become involved in community activities. Furthermore, 78.5% strongly agree that they learned better the content of the course and study through the application of knowledge to real community problems, while 57.1% strongly agree that this was a chance to reflect on their future career and educational objectives. They consider the most important aspects of service-learning to be teamwork, interaction with the client, references for their CV, communication skills, applying knowledge and being able to give of themselves.

Additionally, students had to define in which areas the project had a positive impact. 78.6% of them agreed that it influenced their attitude towards service-learning projects, faculty where SL projects are implemented, their attitude towards their study and work after study. Also, 85.7% of them agreed the project improved the application and enrichment of knowledge gained in the study as well as the ability to work in teams and increased their feelings of personal achievement. Moreover, 71.4% of them agreed the project fostered the desire to help others and a sense of social responsibility and involvement in the society. Finally, 78.6% of them agreed that it increased their self-confidence and skills such as communication, problem solving and persistence as well as the insight into their personal weaknesses and abilities.

In addition, our community partners evaluated the impact of the project at the end of the semester and 78.6% of them strongly agreed or agreed that the SL project was really useful for society. All of them

expressed interest in future collaboration with our institution and our students.

Based on the above described experience, it can be concluded that service-learning offers students a unique opportunity for recognizing the complexity of the concepts of academic courses and research issues. In addition to the adoption of theoretical knowledge, these projects enabled the students to integrate the knowledge with experience. The projects also enabled the community to solve some problems and to strengthen its connection to the University. Finally, the commitment of students to the idea of service-learning made it possible to satisfy the most frequently mentioned student expectations of the Bologna Process: teamwork, fieldwork and work on student's skills, competences and practical implications of gained knowledge.

Future Work

Communities in which businesses are located today are international, diverse and sometimes virtual. On the other hand, the number of e-courses in the universities is growing at an exponential rate, as well as the challenges of today's rapidly-changing, technology-mediated reality. Therefore, both our teachers and students need to prepare themselves for an increasingly challenging e-linked work environment with diverse participants and modes of engagement and to see themselves as a part of a larger social entity in that global work environment.

We assume that service-learning combined with e-learning tools can be used to decrease faculty challenges of course development and facilitation in this new environment and enhance learning. They will be able to use already available courses and a flexible system, such as a content management system, that will accommodate future growth and technology enhancements.

We strongly believe that the Croatian teaching faculty would show more interest for SL if they were able to be part of a SL project during their own study. Hence, our objective is to design service-learning e-courses that will be offered by the Center for Teacher Education at the Faculty of Humanities and Social Sciences and at the university level so that every future school or faculty teacher gets a chance to try this method at the early stage of his or her teaching career.

Finally, we plan to design a workshop for faculty and school teachers that will combine elements of two educational innovations: e-learning and service-learning and share the pointers for the development

of new courses. We also intend to promote the service e-learning method through e-portal UPraVO[xii] (the portal deals with curriculum planning and innovative teaching methods) and through the online teaching support center SPONA[xiii].

Reference

1. Bringle, R.G., & Hatcher, J.A. (2000). Institutionalization of service learning in higher education. Journal of Higher Education, 71(3), 273-290.
2. Bringle, R.G., Games, R., & Malloy, E.A. (1999). Colleges and universities as citizens: Issues and perspectives. In (Eds.) R.G. Bringle, R. Games, & E.A. Malloy, Colleges and Universities as Citizens (pp. 1-16). Boston, MA: Allyn and Bacon.
3. Driscoll, A., Holland, B., Gelmon, S., & Kerrigan, S. (1996). An assessment model for service-learning: Comprehensive case studies of impact on faculty, students, community, and institution. Michigan Journal of Community Service Learning, 3(1), 66-71.
4. European Commission. (2009). Eurobarometer: Students and Higher Education Reform - Survey among students in higher education institutions, in the EU Member States, Croatia, Iceland, Norway and Turkey. Special Target Survey, Brussels, 125 pp. (http://ec.europa.eu/education/higher-education/doc/studies/barometersum_en.pdf)
5. Gray, M. J., Ondaatje, E. H. &, Zakaras, L. (1999). Combining service and learning in higher education: Summary report. Santa Monica, CA: RAND.
6. Hammond, C. (1994). Integrating service and academic study: Faculty motivation and satisfaction in Michigan higher education. Michigan Journal of Community Service Learning, 1(1), 21-28.
7. Holland, B. (1997). Analyzing institutional commitment to service: A model of key organizational factors. Michigan Journal of Community Service Learning, 4(1), 30-41.
8. Jelenc, L., Mikelic Preradovic, N., & Mujevic, D. (2008). Implementing Model of Service Learning in Teaching Strategic Management Course. In Proceedings of the 4th International Conference on Enterprise Odyssey: Tourism - Governance and Entrepreneurship, Zagreb, pp. 381-393.
9. London Communiqué (2007), http://www.ond.vlaanderen.be/hogeronderwijs/bologna/

10. Marullo, S., & Edwards, B. (2000) *From charity to justice*, The American Behavioral Scientist, 43, pp.895-912.
11. Mikelic Preradovic, N., Kisicek, S., & Boras, D. (2010). Evaluation of Service learning in ICT curriculum. In Proceedings of the 2nd Paris International Conference on Education, Economy and Society, Vol. 3, pp. 55-66.
12. Mikelic Preradovic, N. (2009). Ucenjem do drustva znanja: teorija i praksa drustveno korisnog ucenja (Learning for the Knowledge Society: service learning theory and practice). Zagreb: Zavod za informacijske studije Odsjeka za informacijske znanosti Filozofskog fakulteta Sveucilista u Zagrebu. (coursebook).
13. Mikelic, N., & Boras, D. (2006). Service learning: can our students learn how to become a successful student? In Proceedings of the 28th International Conference on Information Technology Interfaces, Zagreb: SRCE, pp. 651-657.
14. Morton, K. & Troppe, M. (1996). From margin to the mainstream: Campus Compact's project on integrating service with academic study. Journal of Business Ethics, 15, 21-32.
15. Stanton, T. K. (1994). The experience of faculty participants in an instructional development seminar on service- learning. Michigan Journal of Community Service Learning, 1(1), 7-20.
16. Strand, K., Marullo, S., Cutforth, N., Stoecker, R., & Donohue, P. (2003a). Community-based research and higher education: Principles and practices. San Francisco, CA: Jossey-Bass.
17. Strand, K., Marullo, S., Cutforth, N., Stoecker, R., & Donohue, P. (2003b). Principles of best practices for community-based research. Michigan Journal of Community Service Learning, 9(3), 5-15.
18. Ward, K. (1996). Service-learning and student volunteerism: Reflections on institutional commitment. Paper delivered at the American Educational Research Association. New York, N.Y.
19. Ward, K. (1998). Addressing academic culture: Service learning, organizations, and faculty work. In R. A. Rhoads & J. P. F. Howard (Eds.), Academic service learning: pedagogy of action and reflection (pp. 72- 80). San Francisco: Jossey-Bass Publishers.

[i] By region we mean the neighboring countries of Bosnia and Herzegovina, Montenegro, Serbia and Macedonia.

[ii] http://www.unizg.hr/bopro/activities/ankete.htm#

[iii] http://www.moj-posao.net/Vijest/70975/Nezaposlenih-u-prosincu-jos-vise/2/

[iv] the term e-learning refers to the use of an e-learning platform: Moodle, Blackboard, WebCT, WebX.

[v] The course is accompanied by a website that serves to promote and archive successful student projects: http:/infoz.ffzg.hr/dku/index.htm. access through http://www.ffzg.unizg.hr/infoz/hr/

[vi] http://www.propisi.hr/print.php?id=9392

[vii] JFDP Regional Conference "Teaching methods and Techniques at the Universities in South Eastern Europe", Zagreb, March, 2009.

[viii] Official Gazette, 87/08.

[ix] http://cal.ffzg.hr/Ispit_informatika_za_drzavnu_maturu/projekt.html accessible through university login

[x] http://www.gimnazija-velika-gorica.skole.hr

[xi] http://www.skola-retkovec.hr/edu-kutak/

[xii] http://domus.srce.hr/iuoun/index.php?option=com_content&task=view&id=37&Itemid=61

[xiii] http://www.unizg.hr/fileadmin/upravljanjekvalitetom/pdf/spona/spona.pdf

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